Sixth Edition

Practical Handbook of Advanced Interventional Cardiology

Tips and Tricks

Thach N. Nguyen • Thuong Dzung Ho
Khiem D. Ngo • Mihas Kodenchery
Gianluca Rigatelli • Marco Zuin
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Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks

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Foreword

Interventional cardiovascular medicine has evolved from an extremely crude method of opening femoral arteries initiated by Dotter, to a field that has now been recognized as having a sufficient fund of knowledge to require boards sanctioned by the American Board of Internal Medicine. From Andreas Gruentzig's development of the noncompliant balloon method, we have seen an explosion of bio-engineering technology. The discipline of interventional cardiovascular medicine has perhaps initiated more registries and clinical trials than any other discipline in medicine. Indeed, the whole emphasis on evidence-based medicine has evolved during the era of interventional cardiology. Many basic science breakthroughs have been stimulated by the advancements produced in interventional cardiology, as well as the problems and complications created by the new technologies. However, no matter how advanced the science becomes the success of solving a patient's problem with interventional techniques usually depends on the operator's technical ability. This ability springs from the wealth of experience the operator has acquired to deal with routine situations as well as complex and almost unique problems that may present themselves. Because of the large number of interventional cardiologists and the rapidly expanding number of procedures that can be performed, it is difficult for many cardiologists to experience all of the situations that can be helpful in building this database.

Dr. Thach N. Nguyen has prepared a remarkable book, rich with tips and tricks for performing interventional cardiovascular medicine procedures. He has enlisted numerous experts on various aspects of interventional cardiovascular medicine to describe their areas of expertise. Rather than let them recite the evidence from registries and trials that are available elsewhere, he forces the contributors to provide the practical tips that they have learned. It is almost as although Dr. Nguyen is trying to simulate the type of scenarios that exist in the catheterization laboratories with new cardiology fellows or less experienced operators. It is the type of advice that he has often given to cardiologists in developing countries who are bringing interventional techniques to help cope with the rapidly expanding new threat in these countries, vascular disease.

Since new techniques are constantly appearing, all operators, experienced or not, can benefit from these tips. Whereas every operator will not agree with every approach to a problem or a complication, it is always instructive to understand many potential approaches. In this regard, the book does a masterful job of collecting not only the authors' experiences but those of many others collected from the published literature, from numerous postgraduate courses, and from one-on-one demonstrations throughout the world.

This book should be a valuable resource to trainees in formal programs that have now evolved in the United States and other countries, as well as the many preceptorships that are the major means of training in other countries. In addition, operators of all levels of experience will find many useful pearls of wisdom.

Dr. Nguyen and his colleagues are to be congratulated for compiling this most practical guide.

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Preface

ADVANCED INTERVENTIONAL CARDIOLOGY: ART AND SCIENCE

By 2026, more than half a century since its modest beginnings, interventional cardiology has evolved into a cornerstone of modern cardiovascular care. Advances in miniaturized equipment, microtechnology, and nano-engineering have made procedures not only effective but also widely accessible and reproducible. Techniques that once required extraordinary dexterity can now be codified into a series of precisely controlled maneuvers—taught to fellows, refined by colleagues, or even programmed into robotic systems. To explain and understand the physical, chemical, biological, and engineering principles, this is a matter of science; to execute these maneuvers with efficiency, compassion, and judgment, this remains an art.

In the catheterization laboratory, a lesion may be crossed and treated with a single wire, balloon, or stent by an experienced operator, while a beginner may require multiple devices for the same task. This is where science and art intersect. Which strategy is best suited for the clinical context at hand? Each operator must assume responsibility for selecting, modifying, or adapting the device, drug, or tactic—sometimes by preference, other times by necessity due to limited availability. While strategies are debated in journals, conferences, and digital platforms, the essential question endures: given the resources and conditions, what is the best course of action for this specific lesion?

In this sixth edition, we aim to provide answers rooted in practical wisdom. Game Plan boxes present procedural frameworks that allow operators to anticipate success and prepare for corrective maneuvers in the event of complications. Tactical Move boxes break strategies into detailed, goal-oriented sequences—beginning with optimal device selection and extending to stepwise solutions when tools underperform. When multiple tactics are viable, critical thinking becomes decisive: a timely tactical shift may spell the difference between success and failure.

To guide decision-making, each maneuver is evaluated in terms of time, cost, and complication risk. Ten extra procedural minutes may translate into an hour of laboratory time. A dollar symbol signals an additional $100 in expense. Two drops of blood denote moderate risk, and three drops mark high risk. Warning boxes capture subtle pitfalls—deceptive signs, judgment errors, or overlooked details that have led to complications. These lessons arise from collective operator experience: not only successes, but also failures, near-misses, and dramatic recoveries. If consistently applied, such insights can elevate outcomes and reduce adverse events. Ultimately, results depend on the interplay of operator skill, available technology, and patient selection.

What is new in this edition is the recognition of a fourth dimension: artificial intelligence (AI). AI now contributes to image interpretation and hemodynamic flow analysis of the new dynamic coronary angiography and ultimately real-time decision support. Machine learning algorithms may detect lesion morphology, assess flow dynamics, and predict growth or regression of severity with a speed and precision beyond human capacity. Yet, AI does not replace the operator; it enhances judgment, extends vision, and provides an additional safeguard when choices are complex. As with any tool, its value depends on how wisely it is applied. The art of interventional cardiology is not diminished but deepened—human insight guided by science, supported by technology, and sharpened by experience.

Today's low-profile balloons and highly torqueable wires allow safe navigation of routine cases by less experienced hands. Yet when anatomies are complex or when simple cases escalate unexpectedly, the seasoned operator consistently achieves superior results. This enduring truth underscores the irreplaceable role of judgment, intuition, and experience—even as technology advances.

As authors and editors, your colleagues and friends, we continue to labor in the cardiac catheterization and interventional laboratory every day. This book is not written from a distance but from lived practice, for novices and veterans alike, for full-time interventionalists and part-time practitioners, and for all who share the same pursuit of excellence. We present these lessons with the intensity of lived experience—successes, setbacks, and recoveries—that mirror the drama of an Italian opera, yet with the hopeful resolution of a Chinese martial arts movie.

Our purpose is straightforward: to practice interventional cardiology responsibly, efficiently, and cost-effectively—guided always by the principle of *primum non nocere*. Whether through human skill, advanced technology, or the emerging partnership with artificial intelligence, the mission remains the same. We are all equal in the shared pursuit of procedural and clinical excellence. That is the essence of this book**.**

Acknowledgment

Copiosa Apud Eum Redemptio This sixth edition is dedicated to the Redemptorists in Vietnam, honoring their faithful service and commemorating the centennial of their arrival. It is offered in thanksgiving for the education and hospitality bestowed upon the lead editor during his early years.

Thach N. Nguyen

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/nguyen/interventionalcardiology

The website includes short videos.

CHAPTER 1

Vascular Access

Pham Nhu Hung, Marco Zuin, Hadrian Hoang-Vu Tran, Nguyen H.K. Nguyen,
Mihas Kodenchery, and Thach N. Nguyen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⏳, <10 min extra; ⏳⏳, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

Gaining vascular access without early or late bleeding at the access site is a major challenge for every operator carrying out diagnostic or interventional cardiovascular procedures.

FEMORAL APPROACH

GAME PLAY

Ideal Location of Femoral Access

The femoral artery is typically palpated below the inguinal ligament, which extends from the anterior superior iliac spine to the pubic tubercle. However, the true position of the inguinal ligament lies 1–2 cm beneath this line. The optimal "landing zone" for vascular entry is located above the femoral bifurcation and below an upper margin that is conservatively defined as several centimeters beneath the lowest point of the inferior epigastric artery (IEA). The IEA descends to, but does not cross, the distal side of the inguinal ligament. Therefore, entry above the lowest point of the IEA's course, which typically ascends to supply the epigastrium, can be used to define an unequivocally high puncture site [1] (Figure 1.1).

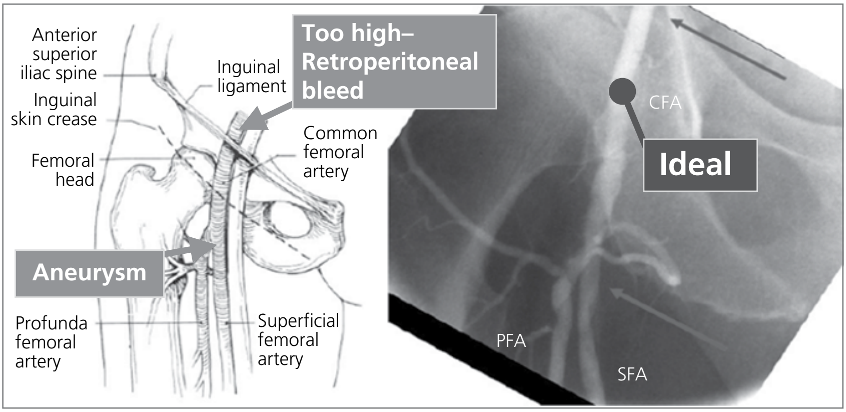

Figure 1.1 Ideal location for puncture of the femoral artery. Source: Reproduced with permission from John Wiley & Sons. CFA, common femoral artery; SFA, superficial femoral artery; PFA, profunda femoral artery.

BEST PLAYERS

Also Known as Standard of Technical Excellence in Femoral Approach

The technique utilizes fluoroscopic visualization of the femoral head in a posterior-anterior projection. The skin puncture is initiated at the lower border of the femoral head, aiming for arterial cannulation at the mid-third of the femoral head. However, even with this approach, punctures below the bifurcation of the common femoral artery (CFA) cannot be entirely avoided due to variability in the femoral artery bifurcation relative to the femoral head. In approximately 77% of cases, the bifurcation occurs below the femoral head, while in about 23% of cases, it is higher. Additionally, 97% of patients have the femoral artery positioned on the medial third of the femoral head, with only 3% having the artery completely medial to the femoral head. Therefore, the most effective way to achieve a near-perfect femoral puncture is through ultrasound guidance [1].

Real-time Actions

Ultrasound-guided puncture In this technique, a needle is initially positioned under fluoroscopy to locate on the skin the best location for puncture, the lower two-thirds of the femoral head (Figure 1.2a).

The equipment used is the Fujifilm SonoSite™ (Bothell, WA, USA), aimed at locating the segment of the CFA immediately proximal to the bifurcation. The femoral artery is identified as a minimally pulsatile, round structure adjacent to another round structure, the femoral vein (Figure 1.2b). When the operator applies pressure with the vascular probe, the femoral artery retains its size, while the femoral vein compresses (Figure 1.2c). The operator tilts the probe up and down to locate the bifurcation with the superficial femoral artery (SFA) and the profunda femoral artery (PFA) (Figure 1.2d). Once the SFA and PFA are located, the puncture site is set proximal to the bifurcation (Figure 1.2b). The needle is positioned at the center of the probe and angled tangentially toward the artery. The metal shadow of the needle is traced, and the tip creates a dent on the anterior wall of the CFA. By advancing forward, the tip enters the lumen, confirmed by strong blood flow back.

Tips and Tricks

*****Selection of the area for puncture under ultrasound** With ultrasound guidance, the operator can identify areas of calcification on the anterior wall of the CFA, which should be avoided for puncture. This is because the needle might penetrate the artery wall, but the subsequent wire may fail to pass through. Manipulating the needle in such cases can lead to unintended vascular access. Additionally, the wire might enter the artery in a subintimal fashion, causing arterial dissection. Therefore, it is advisable to avoid calcified areas and instead target regions without calcification for vessel entry.

****Difficulty in cannulating the arterial sheath** In some cases, inserting a sheath into the artery can be challenging due to the kinking of the wire at the entry site. To address this, push the wire slightly deeper and insert the sheath at a downward angle to access the lumen. Then, slide the sheath up along the artery. This process may require fluoroscopic guidance to ensure the dilator does not bend the wire, creating a pointed tip that could perforate the artery.

Real-time Actions

Fluoroscopically guided micropuncture access The micropuncture vascular access technique involves the use of needles and wires typically in the 21-gauge and 0.018-inch range. For femoral access, these needles are usually 7 cm in length. The outer diameter of this needle is 0.8 mm; in contrast, the 18-gauge needle used by most operators is 56% larger, resulting in as much as six times the blood flow rate through an inadvertent back wall puncture or from an arterial entry with failed sheath placement [2].

The CFA is punctured under fluoroscopic guidance using the mid-third of the femoral head to guide the needle to the anticipated puncture site, although restricting puncture to a point below the centerline of the femoral head may be the most prudent approach. After the initial localization of the bottom of the femoral head, repeat fluoroscopy is performed after the needle has been placed deep in the tissue track, but not yet into the femoral artery, to achieve an ideal location of puncture. The path of the needle can be adjusted several times, if necessary, as it traverses deep into the subcutaneous tissue [2]. Once the needle is in the vessel and there is blood return, some operators perform a limited femoral angiogram via the micropuncture needle using a 3-mL syringe (Figure 1.2e).

If an acceptable CFA access location is confirmed, a 0.018-inch wire is advanced through the needle. A 4-Fr micropuncture sheath is advanced over the wire and exchanged for a 0.035-inch wire to support the passage of a larger sheath size. There are also larger, highly tapered sheaths designed to go directly over the micropuncture wire. This technique allows relatively safe removal of the micropuncture needle or sheath after unfavorable location entry, with manual pressure applied for 3–5 minutes before attempting a new puncture based on the angiogram [2]. http://invasivecardiology.com/files/CilFig5.png

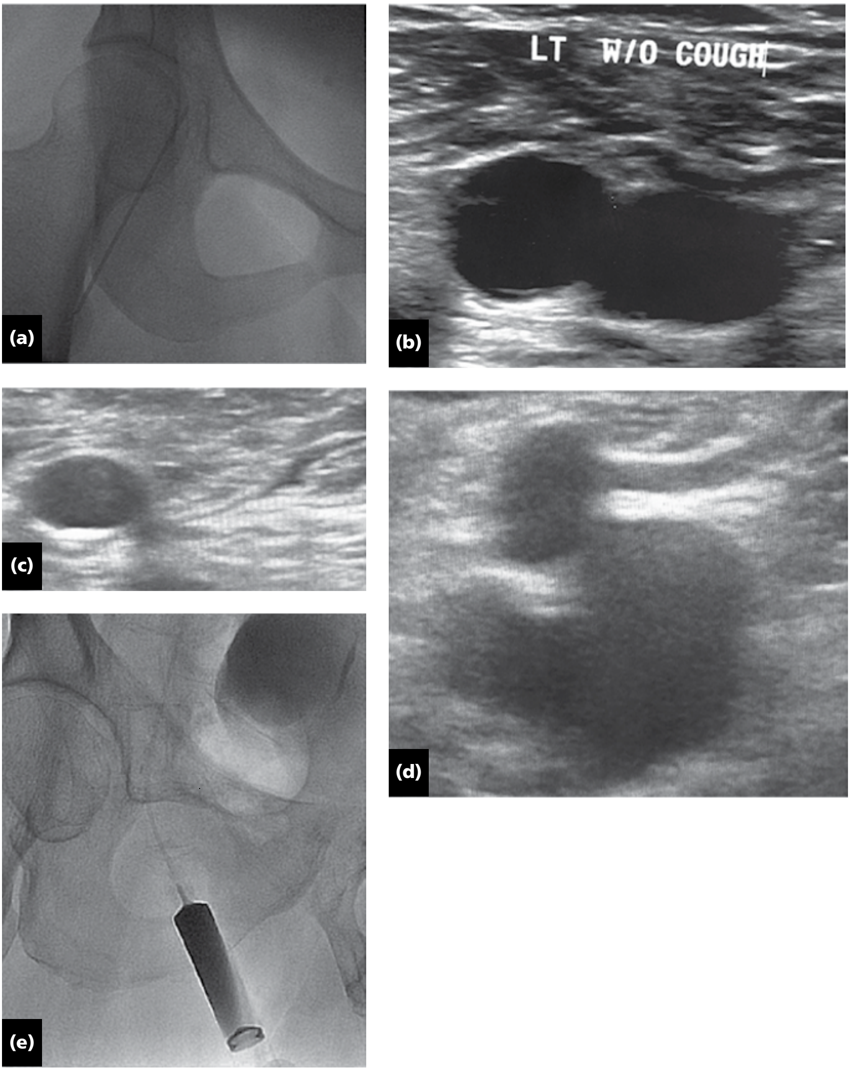

Figure 1.2 (a) A needle is positioned in the right groin area under fluoroscopy, looking for the ideal location for puncture. The tip should be at the lower two-thirds of the femoral head. The reason for this is to locate the upper limit of the area of puncture so the tip of the needle does not end up too high as guided by ultrasound in a patient with a high bifurcation of the deep femoral artery. (b) The femoral artery is recognized as a minimally pulsatile round structure. Next to it should be an oblong structure, which is the femoral vein. (c) Press the vascular probe down: the femoral artery stays the same, while the femoral vein disappears because it is compressed. (d) The superficial femoral artery, profunda femoris artery, and femoral vein at the bifurcation. (e) Before upsizing the micropuncture sheath, perform angiography of the arteriotomy site in the ipsilateral 30–40°. Note vessel morphology. If the location is not “ideal,” pull the sheath out, compress the groin area, and reaccess the artery.

Large sheath Newly developed inflatable vascular sheaths designed to minimize frictional forces caused by large-bore devices have been evaluated. Recent studies suggest that these sheaths may enhance femoral access in patients with access-limited peripheral artery disease. One such sheath is the 19-Fr SoloPath™ balloon-expandable transfemoral access (Terumo, Japan). [3].

DEDICATED EQUIPMENT

E

The 19-Fr SoloPath Transfemoral Introducer (STFI) is a vascular access device that enables large-bore access with technology allowing entry into the femoral artery at a low insertion profile (13 Fr), which then radially expands to a larger profile (19 Fr). The STFI sheath is inserted in a folded state over an expansion balloon dilator. The SoloPath transfemoral system is advanced under fluoroscopic guidance over a stiff wire. It consists of a 25-cm flexible, reinforced polymer sheath pre-mounted over a central balloon dilatation catheter. The specially folded distal two-thirds of the sheath facilitate passage through tortuous and calcified femoral arteries. Once the system is positioned in the abdominal aorta, the SoloPath balloon dilator is inflated for 60 seconds at 20 atm via injection of a 20-mL saline–contrast mix, then deflated and removed, leaving a large 21-F central lumen vascular sheath (Figure 1.3) [3].

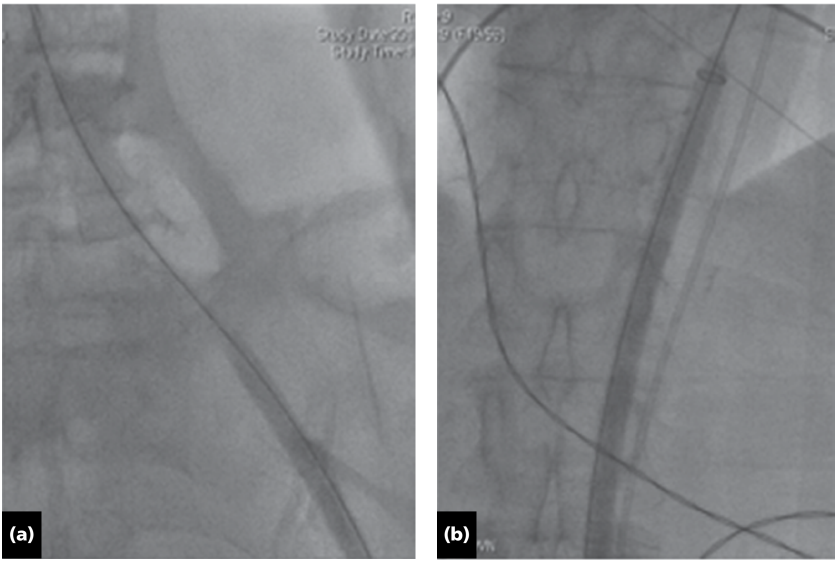

Figure 1.3 Fluoroscopic images of the partially (a) and completely expanded (b) SoloPath expandable sheath.

Tips and Tricks

****Angiography to check the location of femoral entry through a dilator** Some operators avoid injecting through the micropuncture needle due to additional radiation exposure and the risk of losing intraluminal positioning or causing vessel dissection. An alternative approach is to access the vessel with the micropuncture needle, advance the 0.018″ wire, and place the small inner dilator of the micropuncture sheath over the 0.018″ wire. This small dilator can then be used for angiography instead of injecting directly through the micropuncture needle or the larger outer 4-Fr sheath.

***Preparations in obese patients** The femoral pulse at the inguinal crease is an unreliable landmark for the CFA, especially in obese or elderly patients whose crease is often positioned lower than the inguinal ligament. To improve access, the protruding abdomen and panniculus should be retracted and secured to the chest with 3- to 4-inch tapes, which are then anchored to the sides of the catheterization table. Maintaining a thin and taut tissue layer above the artery prevents the needle from being deflected off the projected angle and pathway.

***Directing the needle** When the needle tip approaches the artery, it typically begins to pulsate, except in patients with severe local scarring (such as those with a history of multiple femoral artery cannulations, total hip replacements, or severely calcified arteries due to chronic renal failure). If the hub shifts to the right, the needle should be withdrawn by 1 cm and the tip redirected to the left before advancing further. Conversely, if the hub shifts to the left, the needle tip should be redirected to the right before continuing. If the needle pulsates along the vertical axis, it should be advanced slowly and deeper.

***If the wire cannot be inserted** Most commonly, this occurs when the needle has contacted the contralateral wall. To resolve this, slightly pull or rotate the needle, which may allow the wire to be inserted. If problems persist, it is better to withdraw the needle and re-puncture the artery rather than risk dissecting it with a slippery wire. After the sheath is inserted, if there is strong arterial backflow and the wire cannot navigate the tortuous iliac artery, try gently pulling the sheath back (to disengage it from under a plaque, if that is the issue) and inject contrast. This may help visualize the anatomy and identify the cause of the wire's difficulty. If there is no strong backflow, the sheath may not be in the arterial lumen. In cases of a very tortuous iliac artery, a diagnostic Judkins right (JR) catheter can be cautiously inserted and advanced to help steer the wire. Injections through the JR catheter can also assist in determining why the wire cannot be advanced.

***Sequential order for arterial and venous puncture** The sequence of arterial and venous puncture for right heart catheterization is often a matter of personal preference. We prefer to puncture the vein first, inserting a wire to secure access, followed by puncturing the artery a few seconds later. Afterward, we insert the sheath into both the artery and the vein. Since only a wire is in the vein, there is minimal distortion at the arterial puncture site, which could occur if a venous sheath were in place. A brief period of less than a minute without a sheath will not typically lead to hematoma at the venous site. If the artery is inadvertently punctured first, we cannulate the artery and inject contrast through the arterial sheath. Then, under fluoroscopy, we puncture the vein with the needle placed medially and parallel to the contrast-filled arterial sheath. Alternatively, ultrasound can be used to guide the puncture.

We avoid puncturing the artery with a venous sheath in place because, if the venous sheath is accidentally entered, it may be difficult to control bleeding from the extravascular segment of the sheath with manual pressure. To reduce the risk of creating an arteriovenous fistula (AVF), another strategy is to perform arterial and venous access in separate limbs (e.g. artery in the right groin and vein in the left groin).

****Kinked wire** It is not uncommon for the wire to pass easily into the lumen, but attempts to advance a dilator over the wire may result in kinking at the point of vascular entry. Instead of immediately exchanging the wire, the first preferred maneuver, if the wire is not too crooked, is to advance the wire further. This allows the dilator to be advanced over a straight, stiffer segment of the wire to properly dilate the entry site. If the wire is too soft, the second option is to exchange the softer wire for a stiffer one, using the smallest size 4-F dilator. Ensure that the dilator is advanced under fluoroscopy to verify that it does not bend the wire (which could create a pointed tip) and risk perforating the artery.

****Puncture of pulseless femoral artery** As usual, the artery should be punctured at the midpoint of the medial third of the femoral head. The skin puncture site should be localized using fluoroscopy just below the inferior border of the femoral head to avoid puncturing above the lowest border of the IEA. However, these proportions are only accurate in the anteroposterior (AP) neutral position. Internal or external rotation of the femur can significantly alter the relationship between the femoral artery and the femoral head. Performing the procedure under fluoroscopy is recommended. The most effective technique is to locate the CFA using ultrasound.

Confronting the Challenges

*****Two catheters inserted with single puncture technique** This technique is used in situations like angioplasty for chronic total occlusion when contralateral injection is required. In such cases, an additional puncture, either higher or lower than the initial vascular access site or in the contralateral artery, is recommended. However, if no additional puncture is necessary, the sheath should be exchanged for an 8-F introducer. Two 4-Fr diagnostic catheters can then be inserted and connected to separate manifolds for diagnostic purposes [4].

*****Insertion of intra-aortic balloon pump (IABP) through a diseased iliac artery** When an IABP needs to be inserted and an iliac lesion is present, the lesion should first be dilated. After inserting the balloon pump, stent the lesion once the IABP is removed. If the balloon pump is to be inserted through a previously stented iliac artery, the procedure should be done under fluoroscopy to ensure the balloon does not become trapped by the stent struts. Chronic reendothelialization of the stent struts typically minimizes this risk.

Puncture of femoral bypass graft Problems associated with puncturing an old vascular graft in the femoral area include uncontrollable bleeding and hematoma formation due to the nonvascular nature of the punctured graft, disruption of the anastomotic suture line leading to false aneurysm formation, infection at the graft site, and damage to the catheter, including kinking and separation, caused by scar tissue in the inguinal area and the rigidity of the healed graft material. Inadvertent puncture of the native arterial system may result in entry to a dead-end stump in the common femoral or iliac artery.

Real-time Actions

Bypass graft puncture Since the exact location of the suture line is not known, to avoid puncturing the anastomotic site, it is best to puncture at the proximal end of the inguinal incision site or as close to the inguinal ligament as possible. To prevent catheter kinking at the puncture site, the needle should be introduced at an angle of approximately 30–45° to the estimated long axis of the graft. The most reliable method is to locate the artery using ultrasound. In cases of severe scarring, the entry site may require sequential dilation with progressively larger dilators, up to 1 Fr larger than the sheath selected for the procedure.

Confronting the Challenges

*****Parallel technique** If the native artery is punctured and the wire cannot be advanced due to a dead-end pouch, leave the small 4-F sheath in place as a landmark. Palpate the femoral artery again and try to feel two pulsations: the first is the native artery with the 4-F sheath, and the second, stronger pulsation is from the bypass graft, provided the graft is superficial (though it may be difficult to feel if the graft has a thick wall). Puncture the second pulsatile artery, ensuring you avoid the one with the sheath. This can be done under fluoroscopic guidance to prevent puncturing near the first sheath.

ANTEGRADE PUNCTURE

Antegrade femoral puncture is significantly simplified and more successful when the tissue between the skin surface and the artery is as thin as possible. In obese patients, the fatty panniculus may need to be manually retracted away from the puncture site and taped in place before attempting the puncture. The technique for antegrade puncture of the femoral artery is discussed in detail in Chapter 23.

Real-time Actions

Common femoral artery antegrade puncture The first step is to localize the CFA and its bifurcation under fluoroscopy. The CFA typically overlies the medial third of the femoral head, with the bifurcation located just below the lower border of the femoral head. Once the landmarks are identified, the needle should be directed toward the superior aspect of the femoral head under fluoroscopy to avoid inadvertently puncturing the SFA or the PFA. It is crucial to puncture the femoral artery as high as possible above the bifurcation to allow enough space for catheter exchanges and manipulation of catheters into the SFA. Using fluoroscopy, the intended puncture site is located in the upper or middle third of the femoral head. The femoral pulse is palpated against the femoral head, and local anesthetic is infiltrated 2–3 cm cranial to the puncture site. An 18-gauge needle is then advanced at 45–60°, directed caudally toward the arterial puncture site. Once pulsatile flow is obtained, a soft-tip wire is inserted toward the SFA, following a straight caudal course. Any lateral deviation indicates entry into the PFA. If this occurs, the wire can be withdrawn, and the needle tip is deflected laterally to redirect the wire into the SFA. It is best to perform this procedure under ultrasound guidance.

Tips and Tricks

****Manipulation of the wire** If the wire is inserted into the PFA, it can be withdrawn and redirected by angling the needle tip medially toward the SFA. Alternatively, a wire with a curved tip can be used and manipulated so the tip points toward the SFA. Another option is to exchange the needle for a short dilator with a gently curved tip, which can be directed toward the SFA. This dilator can be slowly withdrawn from the PFA while injecting contrast. Once the orifice of the SFA is visualized under fluoroscopy, it can be selectively catheterized or used to direct a wire into the SFA.

****Puncture of CFA with high bifurcation** In patients with a high bifurcation, a single puncture can result in entry into both the SFA and PFA. If this occurs, the first spurt of blood may indicate the PFA has been punctured. Do not remove the needle completely; instead, slowly withdraw it and watch for a second spurt of blood. This may confirm that the needle is in the SFA when contrast is injected. In rare cases of high bifurcation, the CFA may be too high in the pelvic area to puncture. When the bifurcation is more proximal, puncturing the CFA becomes more challenging, particularly in obese patients. In such cases, it may be acceptable to selectively puncture and cannulate the SFA, provided it appears free of significant atherosclerotic disease and is of adequate size [5].

****Puncture with abduction and external rotation of the thigh** An alternative method to cannulate the SFA is to position the thigh in abduction and external rotation. This maneuver aims to facilitate a more mediolateral puncture site in the CFA. In the typical antegrade puncture, the needle tends to point more toward the PFA, which is lateral to the SFA. However, in the abduction and external rotation position, the needle points more toward the SFA, with the PFA located medial to it. This altered relationship is crucial when observing the wire's course during its selective entry into the SFA. After the procedure, if the patient is punctured in this position, local compression of the artery should be applied while maintaining the thigh in abduction and external rotation, as the puncture site is more mediolateral than usual.

BRACHIAL APPROACH

Although the radial artery is the most commonly used access site in the upper extremity, the brachial artery remains the preferred site for procedures requiring a larger sheath, such as subclavian artery stenting, renal stenting, or aortic aneurysm exclusion. It is recommended to puncture the brachial artery under ultrasound guidance. Radial access is discussed in Chapter 8.

AXILLARY PUNCTURE

Anatomically, the distal third of the axillary artery has three main branches: the subscapular artery, the anterior humeral circumflex artery, and the posterior humeral circumflex artery. The region between the origin of the subscapular artery and the origins of the anterior and posterior humeral circumflex arteries is ideal for percutaneous access to this vessel (Figure 1.4). The axillary artery is preferred over the subclavian artery due to its accessibility outside the chest wall, which allows for manual compression if closure procedures fail. It is also favored over the brachial artery because of its larger diameter and the presence of collateral circulation, which reduces the risk of limb ischemia during the procedure [6].

It is important to be aware of the structures surrounding the axillary artery in this region to prevent potential complications. In front of the artery lie the medial head of the median nerve and the medial antebrachial cutaneous nerve. Medial to the axillary artery is the axillary vein, with the ulnar nerve located between the artery and vein. The medial brachial cutaneous nerve is situated medial to the axillary vein. Laterally, the lateral branch of the median nerve and the musculocutaneous nerve are found. Behind the axillary artery are the axillary and radial nerves [6].

Before gaining access to the left axillary artery, a 7-Fr sheath is inserted into both the right and left radial arteries. An angiogram of the right radial artery is performed to ensure there are no contraindications for using this approach for percutaneous coronary intervention (PCI). Next, an angiogram of the left upper extremity is conducted to confirm the patency of the axillary artery and identify the optimal location for cannulation. This location is in the third part of the vessel, proximal to the origin of the anterior and posterior humeral circumflex arteries and distal to the subscapular artery. A 0.038-inch J wire is then inserted through the left radial artery sheath into the axillary artery. Using the J wire as a fluoroscopic guide, a micropuncture needle is used to access the axillary artery, and a 6-Fr sheath is placed using the modified Seldinger technique (Figure 1.5).

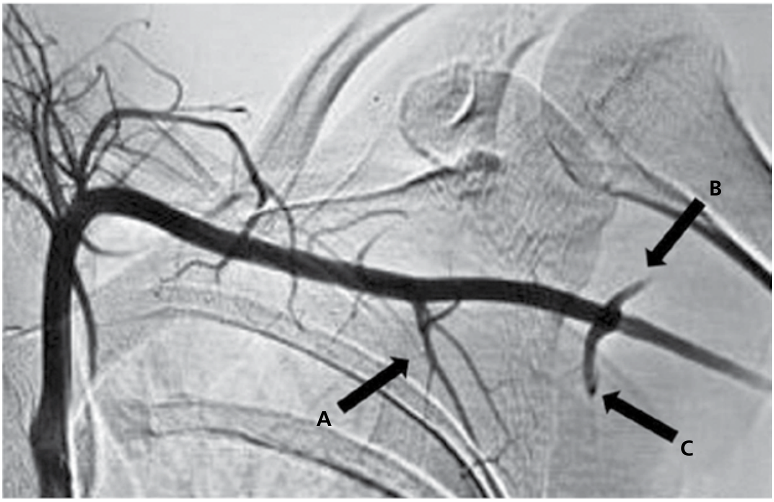

Figure 1.4 Normal subclavian and axillary artery angiogram. The subscapular artery (A) and anterior and posterior humeral circumflex arteries (B and C) are labeled in the third part of the axillary artery [6]. Source: Reproduced with permission from John Wiley & Sons.

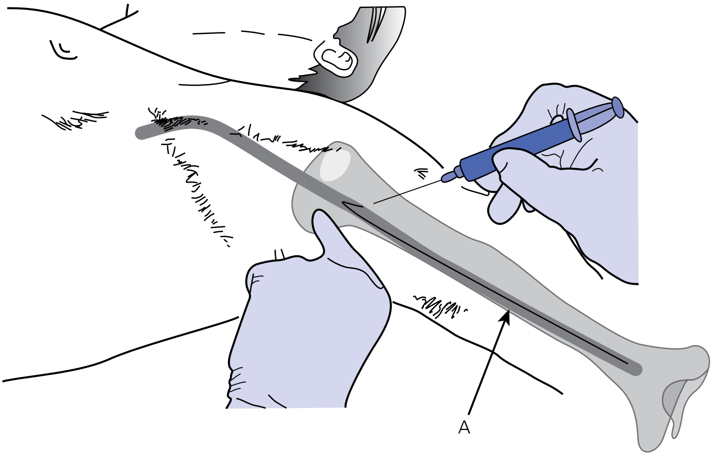

Figure 1.5 Patient in supine position with left arm abducted. A J-wire (A) inserted via a 7-Fr left radial sheath is visualized under fluoroscopy and marks the ideal location for needle insertion between the origin of the subscapular and humeral circumflex arteries. Source: Reproduced with permission from [6]/John Wiley & Sons.

RIGHT HEART CATHETERIZATION IN PATIENTS UNDERGOING PROCEDURE WITH RADIAL APPROACH

The upper and lower arms are prepped and draped in a sterile fashion, using brachial drapes over the wrist and antecubital fossa. Arterial access is obtained via the radial artery, and a sheath is inserted. Position the table so that the antecubital fossa is aligned under the imaging system. Then, inject 5–7 mL of a 50:50 contrast–saline mix into the radial artery under fluoroscopy through the side port of the sheath (the "arterial phase"). After approximately 5–10 seconds, the basilic vein in the upper arm should become visible (the "venous phase"). This is a good time to anesthetize the area over the basilic vein. Using the same micropuncture needle used for radial access, obtain access to the basilic vein, place a 5-Fr radial sheath, and then proceed with the right heart catheterization through the sheath [7].

CLOSURE DEVICES

A closure device can be used after procedures such as PCI, valvuloplasty, or IABP, or when an artery is inadvertently punctured, such as during subclavian artery cannulation. The choice between collagen plugs and suture closure is primarily based on personal preference and experience. Kaolin patches are also available for use when collagen plugs or suture-mediated devices cannot be employed due to factors like massive calcification or severe kinking that prevent the insertion of such devices.

Collagen Plug Device: MYNX®

The MYNX (Cordis Corporation, FL, USA) vascular closure device uses a polyethylene glycol sealant ("hydrogel") that deploys outside the artery, while a balloon occludes the arteriotomy site within the artery. The device is inserted through the existing procedural sheath, and a small, semi-compliant balloon is inflated within the artery. The balloon is then pulled back to the arterial wall, serving as an anchor to ensure proper placement. The sealant is delivered just

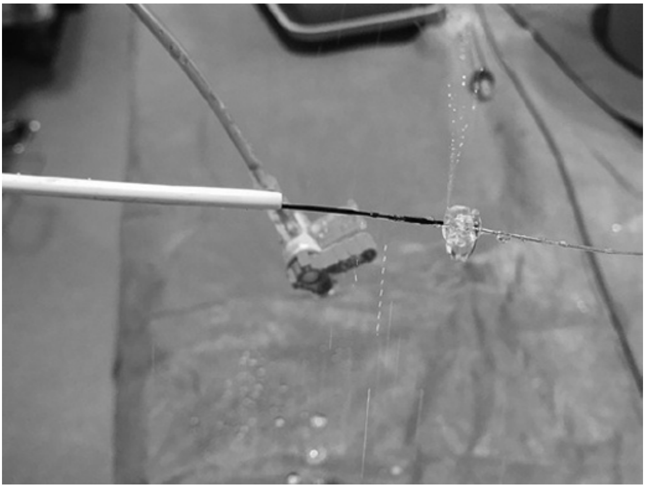

Figure 1.6 The MYNX balloon was punctured when there was a sharp calcium ledge in the common femoral artery.

outside the arterial wall, where it expands to achieve hemostasis. Once hemostasis is achieved, the balloon is deflated and removed through the tract, leaving behind only the expanded, conformable sealant.

One challenge with the MYNX device is that the balloon can be punctured by a sharp calcium ledge in the CFA (Figure 1.6). If there is concern about calcified plaque in the CFA, or if the operator prefers not to use a closure device with an intravascular component, the VASCADE™ (Cardiva Medical, Inc., Santa Clara, CA, USA) may be a better alternative, as it uses a collapsible disk as an anchor. Another potential issue with the MYNX closure device arises when there is a lesion in the mid-external iliac artery. There is concern that the balloon could be inflated at the site of an iliac artery plaque. To address this, inject the balloon of the MYNX device with contrast and position it distal to the iliac lesion under fluoroscopy. Inflate the balloon under fluoroscopy (Figure 1.7a), pull the balloon down (Figure 1.7b), and then deploy the protein plug (Figure 1.7c).

Clip Device: StarClose™

The StarClose (Abbott Vascular Devices; Abbott Laboratories, Redwood City, CA, USA) device achieves hemostasis using a 4-mm nitinol clip implant. The device is inserted into the arterial lumen, and its "wings" are deployed. As the device is withdrawn, the wings are pulled against the arterial wall, confirming proper positioning. The clip is then deployed just outside the arterial wall, where it grasps the edges of the arteriotomy, drawing them together to achieve closure. The StarClose device is indicated for diagnostic and interventional procedures and for closing 5- to 6-Fr arteriotomies, though it has also been successfully used for 7- to 8-Fr arteriotomies.

The Perclose™

Real-time Actions

Preclosure of large arterial access In cases where a large sheath is required (e.g. for aortic valvuloplasty), untied sutures can be pre-placed using the Perclose (Abbott Vascular, Chicago, IL, USA) percutaneous suture delivery system prior to sheath deployment. A 5- to 6-Fr sheath may first be used for arterial angiography to assess the anatomy of the CFA, ensuring it is free from calcification and not near any lesions. Once suitable anatomy is identified, the suture device is used to place the untied sutures. At the end of the procedure, the "purse-string" suture is tightened around the arteriotomy to achieve hemostasis [8].

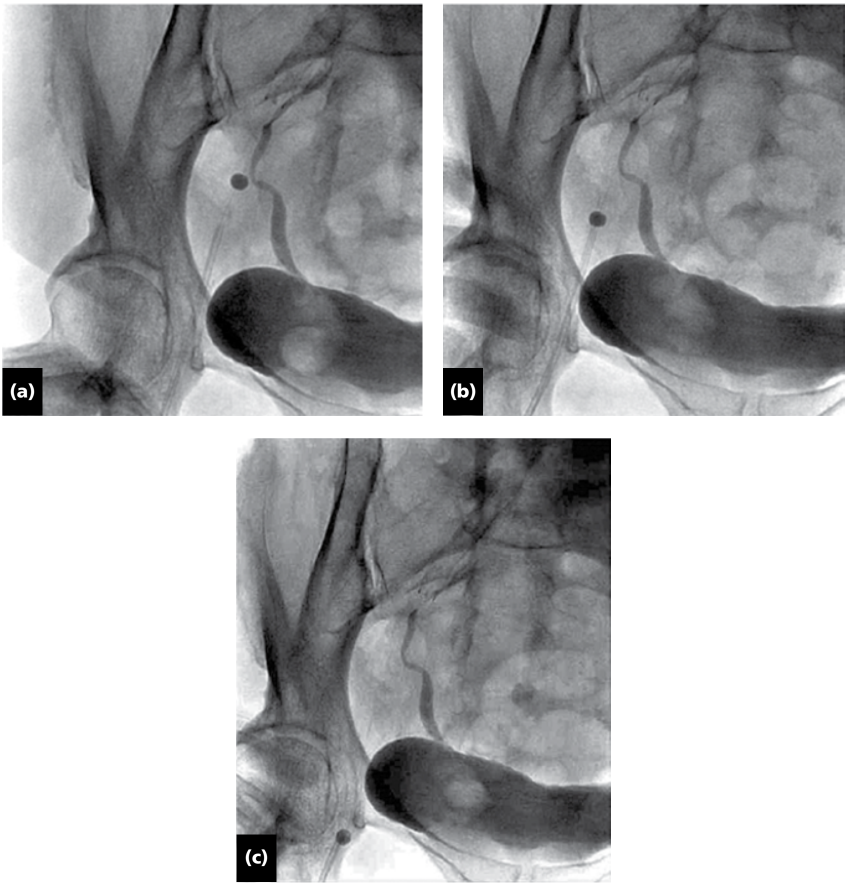

Figure 1.7 (a) The balloon was injected with contrast, positioned, and inflated under fluoroscopic guidance below the lesion in the iliac artery. (b) The balloon and the sheath were pulled down under fluoroscopy. (c) The balloon is at the wall, and the protein plug is ready to be deployed.

Preclosure of large venous access The "preclosure" technique involves preloading a 6-Fr Perclose suture closure device into the femoral vein after access with a 6- or 8-Fr dilator, prior to the insertion of a 14-Fr venous introducer sheath for antegrade aortic valvuloplasty. The placement of the Perclose device within the venous system is confirmed either by back-bleeding from the marker port or by contrast injection through the port. The needles are then removed, and the sutures are clipped. After the sutures are deployed, a wire is placed into the femoral vein through the Perclose device. The wire is used to exchange for a 14-Fr sheath, while the sutures are laid alongside the puncture and covered with betadine-soaked gauze. Upon completion of the valvuloplasty procedure, a wire is passed through the 14-Fr sheath to secure the vessel in case of suture closure failure. Heparin is not reversed. The sheath is removed through the sutures, and the sutures are tied around the wire. If hemostasis is achieved, the wire is gently removed, and the knot is pushed further to complete the closure [8].

Tips and Tricks

*****Differences in technical details for preclosure of venous access** Since veins have thinner walls than arteries, less tension is applied when retracting the Perclose device for venous closure compared to arterial closure. The device foot can securely contact the vessel wall with steady pressure, using less force than is required for arteries. Back-bleeding through the marker port is seen in most cases, although it is less pronounced than in arterial closure due to the lower pressure in the venous system. Typically, a slow dribble of blood is noted from the marker port. There may be a delay in the onset of back-bleeding, which is further influenced by the low venous pressure. This delay can be minimized by having the patient take a deep breath or perform the Valsalva maneuver [8].

*****Double Angio-Seal™ closure for a 10-F vascular access** Although Angio-Seal (Terumo, Somerset, NJ, USA) labeling indicates compatibility with procedural sheaths of 8 Fr or smaller, the device has been successfully used to close 10-Fr arteriotomies with a "double wire" technique. In this approach, at the end of the procedure, both the Angio-Seal wire and a second, additional wire are inserted through the sheath. The Angio-Seal is deployed as usual using the primary wire, leaving the second wire in place. If hemostasis is achieved, the second wire is carefully removed while maintaining pressure on the collagen plug. If hemostasis is not achieved, the second wire serves as a "backup" to allow for the deployment of a second Angio-Seal device next to the first [9].

*****Double MYNX closure for 14-F arterial access** Two MYNX closure devices were simultaneously passed through the 14-F arterial sheath, and both distal semi-compliant balloons were inflated with a 3:1 saline-to-contrast mixture to facilitate balloon visualization. Under fluoroscopic guidance, the MYNX balloons were withdrawn to the distal end of the 14-F sheath, and then both balloons and the sheath tip were pulled back to the previously visualized arteriotomy site. The polyethylene glycol sealant from each MYNX device was advanced into the 14-F sheath sequentially, and the sheath was then withdrawn, allowing the sealant to hydrate and expand in an extra-arterial position over the arteriotomy. After 2 minutes, the balloons were deflated, the MYNX delivery catheters were removed, and manual compression was applied for an additional 2 minutes. Closure of the 14-F arteriotomy was confirmed to be complete, with no bleeding, vascular compromise, or hematoma on inspection [10].

Discriminating Differences

Which vascular closure devices for which patients? Vascular closure devices (VCDs) are not suitable for all patients, and caution is necessary when considering their use in individuals with peripheral vascular disease, extreme obesity, small femoral arteries (diameters <4–5 mm), or those with arterial cannulation at or below the bifurcation (because there is no bony structure behind the SFA to support manual compression if VCDs fail). In addition to patient-specific and arterial factors, the mechanism of action of VCDs must also be considered, particularly the presence of an intravascular component in the closure device.

Devices with significant intravascular components, such as the Angio-Seal device, are not recommended for bifurcation punctures due to the risk of obstructing smaller branches by the intravascular portion. Furthermore, accurately aligning the intravascular part can be challenging due to the complex angles at the bifurcation site. There is also a risk of intravascular deployment of the collagen plug. Therefore, access-site closure remains challenging in patients with bifurcation punctures. Devices without significant intravascular components, such as the StarClose or MYNX devices, are particularly beneficial for these patients. Additionally, VCDs should not be used in high arterial punctures, as they have been associated with an increased risk of retroperitoneal hemorrhage, with an odds ratio as high as 17:1 [11].

Confronting the Challenges

Suspecting intra-arterial deployment of collagen plug During deployment of an Angio-Seal device, intra-arterial deployment of the collagen plug can be caused by inadequate tension on the suture, vigorous tamping, too deep insertion of the device into the artery so that the anchor is caught in the posterior wall, and so on. Suspicion of a problem is aroused when there is a long travel distance of the tamper tube or continued bleeding [12].

Confronting the Challenges

*****Management of intra-arterial deployment of collagen plug** In a case report of possible intra-arterial deployment of the collagen plug by the Angio-Seal device, it was observed that the tamper tube was inserted much deeper than usual. Despite this, the patient continued to bleed, prompting the placement of a tension spring as per usual practice. A hemostat was simultaneously applied to secure the end of the suture, and a FemoStop™ (RADI Medical Systems, Uppsala, Sweden) compression device was placed above the Angio-Seal to control the bleeding. After 4 hours, the anchor, composed of absorbable polymer material, softened and became pliable. To prevent potential embolization of the anchor and collagen plug if the suture broke during traction, a hemostat was placed at the level of the skin. Steady traction was then applied to the suture, perpendicular to the femoral artery, ensuring that pressure was not excessive. After 20 minutes, the plug was successfully removed. FemoStop was reapplied, and hemostasis was achieved [12]. Another method for removing an embolized plug is using a snare to extract it (Figure 1.8a–c). Management is summarized in Box 1.1.

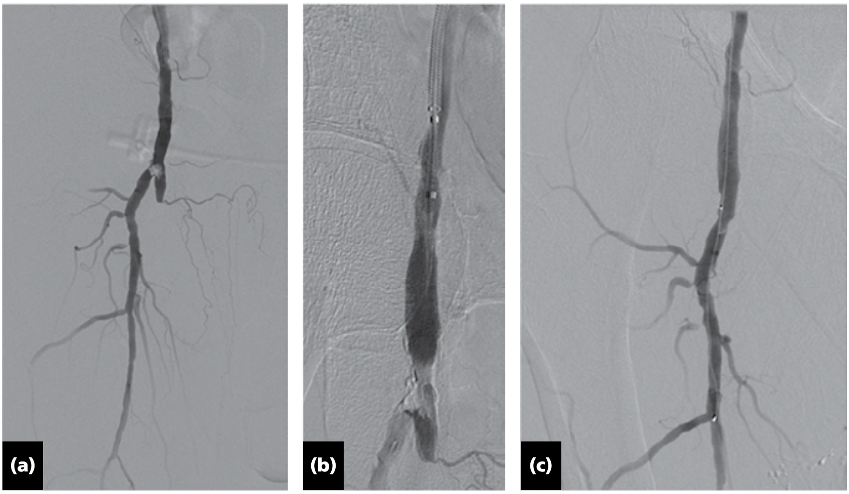

Figure 1.8 (a) The patient underwent diagnostic catheterization of the carotid artery. The right femoral angiogram was not performed at the end of the case because of a high creatinine level 1.8 mg/dL. An Angio-Seal device was deployed. One hour later, the patient had severe right leg pain. The femoral angiogram showed acute occlusion of the superficial femoral artery at the bifurcation. (b) and (c) A snare was advanced to the bifurcation area and successfully removed the embolized plug.

BOX 1.1 WHAT TO DO IF COLLAGEN IS INSERTED INTRA-ARTERIALLY

1. Prevent the problem: always maintain tension on the suture and avoid tamping with excessive force.
2. Recognize the problem: absence of resistance during tamping and inadequate hemostasis are clues.
3. Duplex ultrasound can document intra-arterial collagen.
4. Apply tension on the string in the usual fashion; secure the suture with a hemostat at skin level to add security.
5. **Do not cut the suture:** embolization of the anchor and plug may occur.
6. If there are signs of embolism and thrombosis, obtain a vascular surgery consultation.
7. Wait at least 4 h to allow softening of the anchor.
8. Exert steady vertical traction on the suture with approximately 10 lb of force.
9. If removal of the device is achieved, maintain manual compression to achieve hemostasis.
10. A FemoStop device should be ready for rapid deployment after the device is removed.
11. Remove the collagen plug using an atherectomy device (if needed).

Source: Adapted from [11].

COMPLICATIONS

Hematoma

The frequency of hematoma increases with increasing size of the sheath, level of anticoagulation, and obesity of the patient. Surgical evacuation is not required, even for large hematomas, unless there is undue tension on adjacent structures or in the case of a truly huge hematoma. Surgical evacuation and arterial repair are required when the hematoma is pulsatile and expanding, an indication of communication between the hematoma and the femoral artery, and the presence of a false aneurysm.

Arteriovenous Fistula

This happens rarely (>0.4%) when the puncture is made where the artery overlies the vein. Most small AVFs are asymptomatic and usually close spontaneously. A large AVF with symptoms of high-output failure needs to be corrected surgically.

Acute Arterial Thrombosis

Occlusion of the femoral artery may occur due to thrombosis or local arterial injury. It happens mostly in women with small femoral arteries that are completely blocked by the catheter during the procedure and in patients whose SFA is catheterized rather than the CFA.

Confronting the Challenges

Mechanical thrombectomy for acute thrombosis If thrombosis of the femoral artery is suspected, access is obtained from the contralateral side, and 5000 units of heparin are given. A 6-F crossover sheath is placed in the external iliac artery over a 0.035-inch stiff Amplatz guidewire. The occluded/thrombosed/embolized segment of the artery is crossed with a 0.014-inch or 0.018-inch wire. Any thrombectomy device can then be introduced over the wire, and an attempt is made to remove thrombi. If normal distal flow is established without any residual stenosis, the procedure is terminated. If there is still residual thrombus, then the segment is dilated with a peripheral balloon, and if the post-percutaneous transluminal angioplasty (PTA) result is not optimal, a self-expanding stent may be deployed [13].

If a heavy thrombotic burden persists after mechanical thrombectomy, then tissue plasminogen activator (tPA) 0.05 mg/kg can be given along with heparin through a multi-hole delivery catheter (e.g. 5-Fr Mewissen). Four hours later, an angiogram can be carried out to check the progress, and if there is still a thrombus, the patient can undergo a longer infusion (12–18 hours) [13].

Limb Ischemia

Patients who develop acute limb ischemia after femoral artery catheterization must be carefully and immediately evaluated by duplex ultrasound. Angiography is mandatory and should not be delayed. The purpose of angiography is to identify the location (aortoiliac inflow circulation, infrainguinal outflow circulation, or runoff circulation) and cause (dissection, thrombosis, distal embolization, or sheath/vessel mismatch) of ischemia since these factors will help determine the treatment strategy (e.g. vascular surgery, percutaneous revascularization, thrombectomy, or intra-arterial thrombolytic infusion). In most cases, digital subtraction angiography is best, because cine angiography may not permit adequate visualization of the runoff circulation [14].

Confronting the Challenges

*****Temporary relief of iatrogenic ischemic limb: percutaneous technique for in vivo femoral artery bypass** During PTA of high-risk patients, if acute limb ischemia arises during femoral artery catheterization, the antegrade sheath in the femoral artery and the retrograde sheath in the contralateral CFA can be connected using standard 12-inch pressure tubing and a male-to-male adapter. This technique is considered a temporary method to restore blood flow, minimize the metabolic consequences of acidosis and muscle necrosis, permit more definitive percutaneous or surgical revascularization as indicated, and allow the use of devices for invasive hemodynamic support when such devices cause limb ischemia and there are no other therapeutic alternatives [14].

Preventing limb ischemia Steps to prevent limb ischemia include (1) careful examination of femoral pulses and bruits before catheterization; (2) angiography prior to insertion of any hemodynamic support device; (3) angioplasty and stenting of suitable aortoiliac stenoses before device insertion; and (4) use of a sheathless IABP, which might reduce the risk of ischemic complications in patients with diffuse aortoiliac disease or small vessels [14].

Retroperitoneal Hematoma

The clinical clues of retroperitoneal hematoma (RPH) include hypotension without apparent reason, blood loss without possible source, suprainguinal tenderness and fullness, and flank discomfort. A small hematoma is not able to cause any hemodynamic disturbances or any increase of the retroperitoneal cavity pressure to cause neurological symptoms (Figure 1.9a).

An RPH near the iliopsoas muscle will often present severe muscle spasms, resulting in severe pain in the groin or hip area with radiation to the lower back and anterior thigh on any attempt to extend the hip. With an expanding hematoma, femoral nerve compression typically occurs along the iliopsoas gutter with a characteristic pain in the anteromedial thigh. Usually, bleeding into the retroperitoneal site is self-limiting unless the patient is anticoagulated.

Mechanism of clinical symptoms The femoral nerve is formed by the second to fourth lumbar nerve roots and provides motor innervation to the quadriceps, sartorius, pectineus, and iliopsoas. It supplies sensory innervation to the anteromedial thigh and medial leg. The nerve lies in the groove between the iliacus and psoas muscles. Entrapment of the femoral nerve by an iliopsoas hematoma is the most likely cause of femoral nerve palsy. Weakness of the quadriceps muscle and decreased patellar reflex are the most striking findings on physical examination [15].

Management of RPH includes stopping heparin and reversing anticoagulation with protamine, then rapid fluid resuscitation to reverse hypovolemia. A transfusion may be needed. The decision to intervene with evidence of persistent hemorrhage remains controversial, and a vascular surgical consultant should be involved at an early stage. The RPH will often have a tamponade effect on the site of persistent hemorrhage. Surgery could potentially reduce the effect of the tamponade with catastrophic consequences. There is a trend toward such

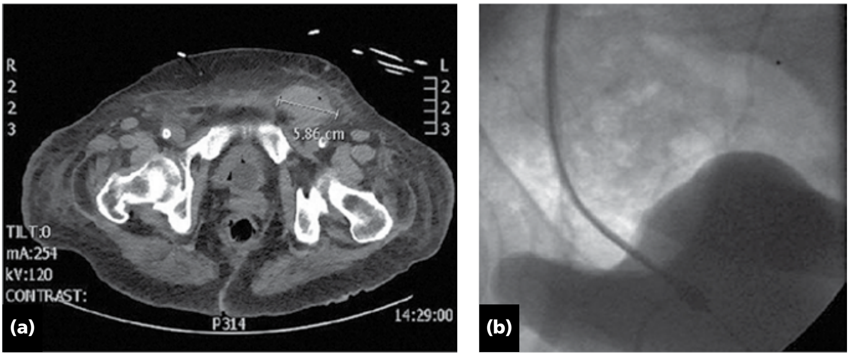

Figure 1.9 (a) A hematoma was seen in the left groin area (in the left upper corner of the CT scan of the abdomen). (b) A dented bladder due to retroperitoneal hematoma. It looks different from the normally round shape of the bladder.

techniques as stent grafts or intra-arterial embolization to halt the persistent hemorrhage. Open surgery should be considered if the patient remains hemodynamically unstable and the previously mentioned measures have been unsuccessful [16].

Discriminating Differences

Medical and surgical management of retroperitoneal hemorrhage After PCI, the presence of RPH was associated not only with a higher frequency of post-procedure cardiac complications, including myocardial infarction and congestive heart failure, but also with a higher frequency of infection and/or sepsis, gastrointestinal bleeding, and contrast nephropathy. Of the patients who developed RPH, 92.3% were treated medically and 7.7% underwent surgical repair. A trend toward higher in-hospital mortality was observed in patients with RPH treated surgically than in those treated medically, possibly reflective of the fact that a surgical approach might be performed in more unstable patients in whom fluid resuscitation and blood transfusions are inadequate in reestablishing a stable hemodynamic status [17].

Tips and Tricks

****How to detect RPH in a 1-second maneuver?** An AP view of the pelvic area under fluoroscopy may give a clue to the problem. Usually, the bladder is seen as round and filled with contrast. If the opacified bladder is seen displaced and its round shape is dented, RPH is strongly suspected (Figure 1.9b). However, a significant quantity of blood needs to be sequestered before unilateral external compression of the bladder occurs.

Real-time Actions

How to seal a perforation with a balloon The initial angiogram reveals a laceration of the IEA arising at the origin of the right CFA. A 6-Fr crossover sheath is positioned in the right external iliac artery, and a 6-Fr right Judkins-4 guide is then advanced over the crossover sheath to select the ostium of the lacerated IEA. A 0.014-inch Balanced Middleweight wire (Abbott Vascular Devices; Abbott Laboratories, Redwood City, CA, USA) is advanced into the IEA, and the tip is positioned distal to the lacerated area. A 2 × 10 mm balloon catheter is then advanced and parked at the level of the laceration and inflated at 1 atm on three sequential occasions for up to 20 minutes. Adequate balloon occlusion can be confirmed by injecting contrast through the guide. Nevertheless, if the angiogram reveals persistent and significant bleeding after each balloon deflation, attempts should be made to thrombose the lacerated vessel in order to stop the hemorrhage.

How to close a perforation with microcoil or injection of thrombin Microcoils can be used for closure of the small artery. If there are no microcoils available, infusion of thrombin through the lumen of the inflated over-the-wire balloon can be done. Careful positioning and sealing of the vessel are confirmed with injection of contrast from the guide and through the balloon lumen to ensure that there is no passage of contrast from the vessel lumen into the CFA. Thrombin-JMI (Jones Pharma, St. Louis, MO, USA) is diluted in normal saline at a concentration of 50 IU/mL. Subsequently, a total of three consecutive doses of 100 IU of thrombin can be administered through the balloon catheter lumen. Contrast can be injected through the balloon lumen after each dose of thrombin. When there is no further evidence of blood flow and no extravasation of contrast through the laceration, the balloon can be deflated [18] (Figure 1.10a–d).

Perforation

If a balloon bursts and perforates a peripheral artery below the inguinal ligament, local bleeding can be controlled by direct pressure. In the case of higher perforation, a large peripheral balloon should be inflated above or at the rupture site to stop the bleeding and to seal the puncture site [19].

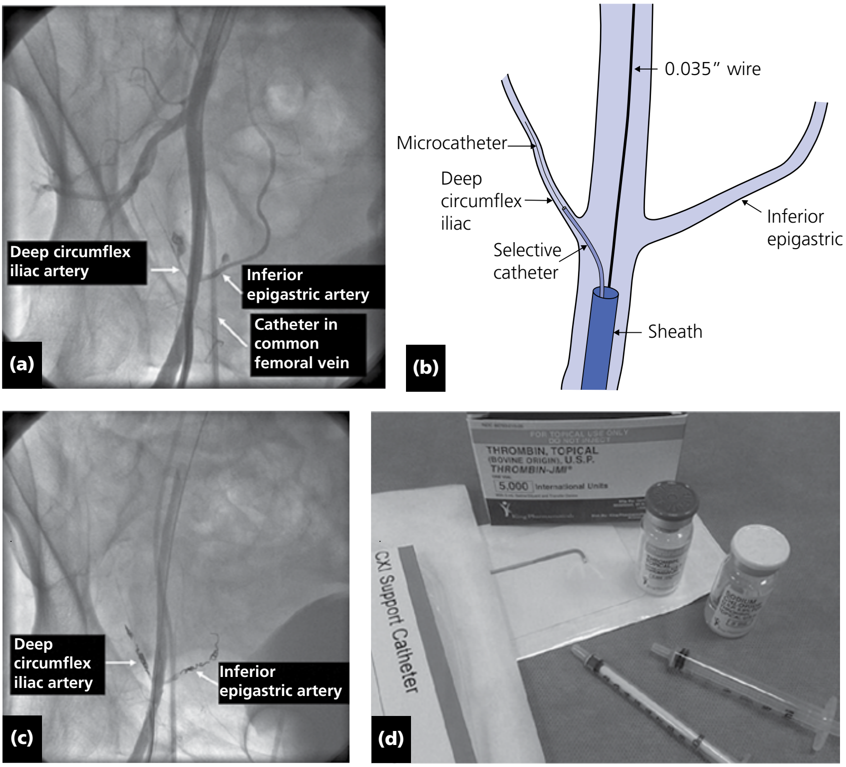
Deep circumflex iliac artery
Inferior epigastric artery
Catheter in common femoral vein
(a)
0.035″ wire
Microcatheter
Deep circumflex iliac
Selective catheter
Inferior epigastric
Sheath
(b)
Deep circumflex iliac artery
Inferior epigastric artery
(c)
FOR TOPICAL USE ONLY
THROMBIN, TOPICAL
(BOVINE ORIGIN), U.S.P.
THROMBIN-JMI
5,000 International Units
CXI Support Catheter
(d)

Figure 1.10 (a) After coronary stenting, an angiogram of the common femoral artery showed bleeding at the deep circumflex iliac artery, and the inferior epigastric artery. (b) A selective catheter was advanced into the deep circumflex iliac artery and with it a microcatheter was positioned near the perforated area. (c) Microcoils were delivered into the deep circumflex iliac artery and the inferior epigastric artery and successfully closed the perforations. (d) How to mix thrombin: use 2–3 mL of the patient's blood mixed with 1000–2000 units of thrombin. Inject the thrombin–blood patch into the track.

Real-time Actions

How to seal a perforation with a covered stent Access is obtained through the left femoral artery for a retrograde approach to right iliofemoral angiography. A 6-Fr internal mammary catheter is inserted over a 0.035-inch Glidewire™ (Terumo Medical Corp., Somerset, NJ, USA), and this wire is used to cross into the right SFA. The Glidewire is then exchanged for a 0.035-inch Amplatz super stiff wire, and an 8-Fr, 65-cm long Arrow-Flex® sheath (Teleflex, Wayne, PA, USA) is advanced under fluoroscopic guidance over the aortoiliac bifurcation to provide adequate support in the right external iliac artery. Balloon tamponade of the perforation site is performed by inflating a balloon at 2 atm for 5 minutes, although persistent extravasation of contrast continues. An undersized self-expanding covered stent is then placed across the perforation site, where contrast leakage persists. The stent graft is subsequently post-dilated with a balloon at 8 atm, achieving complete hemostasis and resolving the free-flow contrast into the retroperitoneum (Figure 1.11a–c).

Pseudoaneurysm

The primary cause of pseudoaneurysm (PA) is inadvertent puncture of the SFA. A femoral PA develops when the puncture site fails to close, allowing continuous blood flow into a small perivascular space surrounded by fibrous tissue and hematomas. It is suspected when a laterally

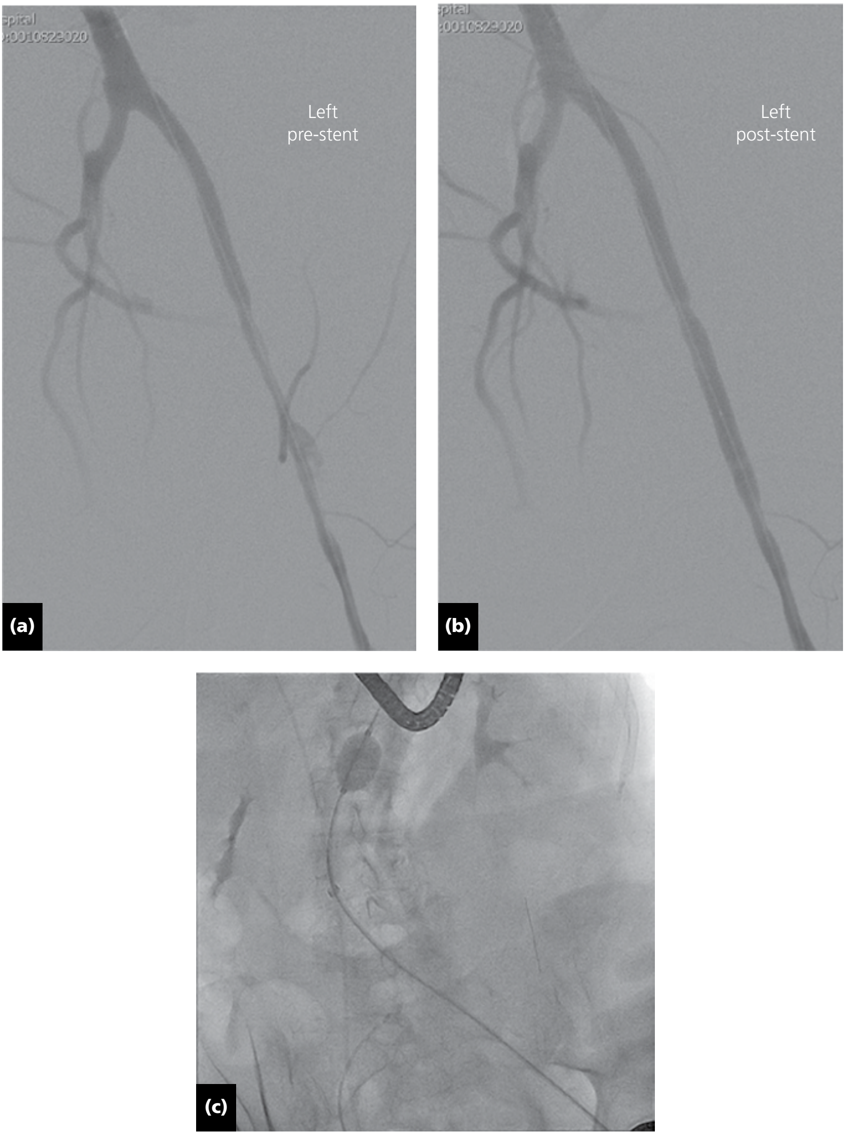

Figure 1.11 (a) and (b) Bleeding from the left external iliac artery treated with a covered stent. (c) When there is a lot of bleeding, a large aortic balloon can be inflated at the distal end of the aorta to stop the bleeding through the iliac arteries.

pulsatile mass, an arterial bruit, and tenderness at the vascular access site are present. Confirmation is made through ultrasound, which typically shows a hypoechoic cavity with blood flow through a neck, visible by color Doppler. Pulsed Doppler reveals to-and-fro flow between the cavity and the arterial lumen during systole and diastole. Hematomas appear as hypoechoic collections without Doppler flow movement.

Indications for aggressive management include a large PA size, growth in size, or the need for continued anticoagulation. Small PAs (<3 cm in diameter) often close spontaneously, likely due to thrombosis, with follow-up ultrasound 1–2 weeks later showing spontaneous thrombosis, eliminating the need for surgical intervention. PAs greater than 3 cm in diameter are less likely to resolve on their own. If the PA persists beyond 2 weeks or increases in size, the risk of femoral artery rupture necessitates intervention. The simplest method of treatment is using a mechanical compression device, such as FemoStop. The success rate for this approach is 74%, with a mean compression time of 33 minutes. In cases of failure, ultrasound-guided compression can be employed successfully.

Contraindications to mechanical compression are listed in Box 1.2. Ultrasound-guided compression is commonly used, with success dependent on anticoagulation status and the ability to easily visualize and compress the PA. The most recent treatment modality involves injecting thrombin into the PA, a quick, simple, and painless technique. Surgery is rarely required unless other management strategies fail. In rare cases, thrombin may enter the peripheral circulation, leading to intra-arterial thrombosis (seen in less than 2% of cases), which is usually managed conservatively. The ranking of each method's effectiveness in excluding a femoral PA is summarized in Box 1.3.

BOX 1.2 CONTRAINDICATIONS TO MECHANICAL COMPRESSION FOR PSEUDOANEURYSM

1. Sign of local infection
2. Critical limb ischemia
3. Large hematomas with overlying skin necrosis
4. Injuries above the inguinal ligament

BOX 1.3 TACTICAL MOVE

Best options for exclusion of femoral pseudoaneurysm

1. ⌛ **FIRST best option:** Mechanical compression therapy if there is no thrombin available
2. $⌛ **SECOND best option**: For patients **who** fail empiric compression: ultrasound-guided compression
3. $⌛💧 For patients on anticoagulants or **having** contraindication to compression: percutaneous injection of thrombin

Femoral Dissection

Femoral artery dissection is a recognized complication of the Perclose (and other) closure devices and could occur if the needles are deployed too early and they interact with the posterior wall of the vessel or if the needles are deployed through a plaque in the anterior wall of the vessel. Meticulous attention and gentle manipulations while puncturing the artery and advancing the wire may lower the risk of access site complications. Routine femoral angiography during cardiac catheterization could lead to early diagnosis not only of arterial dissections but also of other complications, such as bleeding from laceration of the IEA.

Open surgical repair has historically been the treatment of choice for flow-limiting femoral artery dissections, but percutaneous techniques are increasingly being used to treat these injuries. Stenting of the CFA is not recommended because of the high risk of stent fracture.

Balloon angioplasty or atherectomy of the CFA might be better alternatives to stenting if they provide an acceptable angiographic result.

Patients with non-flow-limiting iliac artery dissections can often be treated conservatively because the blood flow tends to "tuck" iliac dissections caused during retrograde insertion of catheters, wires, or other equipment. Conservative management for non-flow-limiting dissections consists of bed rest with follow-up noninvasive imaging and clinical exams. If dissections are flow-limiting, then stenting (using self-expanding stents for the external iliac artery or either self-expanding or balloon-expandable stents for the common iliac artery) may be the treatment of choice.

CASE REPORT

Retrograde Abdominal and Thoracic Dissection from the Iliac Artery

A patient with suspected coronary disease was prepared for cardiac catheterization via the femoral approach. A standard right femoral artery puncture was performed, and the wire passed easily to the mid-aorta. However, there was difficulty advancing the wire and the catheter beyond the aortic arch, and the procedure was abandoned. Half an hour later, the patient complained of severe back pain and became temporarily hypotensive. A computed tomography (CT) scan confirmed the aortic dissection, with the entry point in the iliac artery extending to the aortic arch. Initially, the patient was managed conservatively, but she had recurrent transient episodes of severe back pain associated with transient hypotension (75/40 mmHg), so, under fluoroscopic guidance, a 10 mm × 4 cm stent was placed in the right common iliac artery via the contralateral femoral approach. The new stent occluded the entry point. Follow-up CT showed thrombosis of the false lumen and sealing of the dissection flap. The favorable outcome in this patient was likely due to two factors: (1) the retrograde direction of the dissection, in contrast to the antegrade direction of the usual spontaneous aortic dissection and (2) the absence of re-entry, which contributed to stagnation of blood flow in the false lumen, resulting in the formation of thrombus and the rapid disappearance of the retrograde dissection [21].

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CHAPTER 2

Coronary Angiography

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Truong Trung Duc, Viet M. Vo, and Thach N. Nguyen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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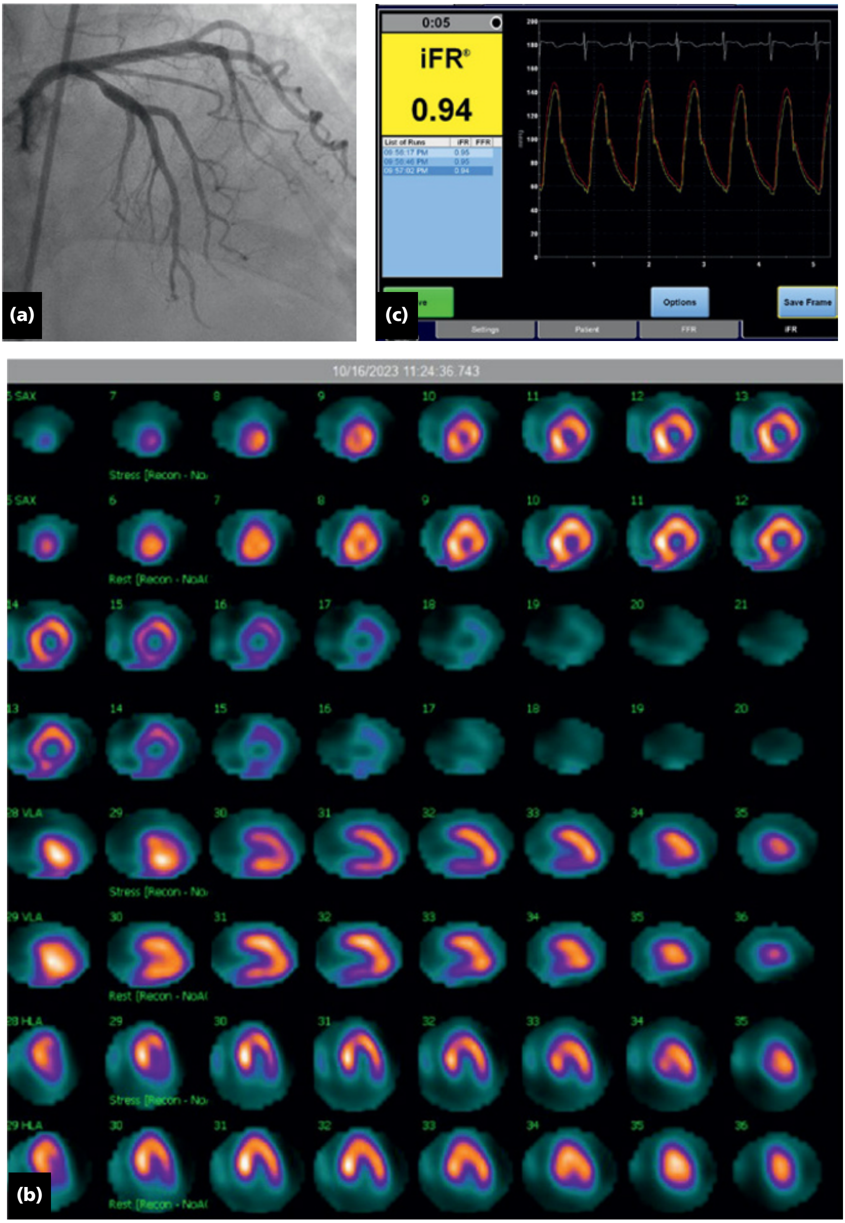
CHALLENGES

The primary goal of coronary angiography is to deliver a clear visualization of arterial lesions through two orthogonal views. This method allows for precise morphological evaluation, facilitates objective comparisons of post-intervention outcomes, and enables early detection of complications. Accurate imaging of the ostial segment of the target artery, along with the orientation, trajectory, and calcification of proximal segments, is crucial for planning the precise and timely navigation of diagnostic and interventional devices. However, two-dimensional angiography can inaccurately assess the hemodynamic significance of a lesion due to factors such as angulation, lesion eccentricity, foreshortening, and the complex anatomy of bifurcations. When a vessel bends in multiple planes, no single angiographic view can overcome the issue of multiple foreshortenings. Consequently, the physician must customize the degree of angulation to best visualize the problem area.

BEST PLAYERS

aka Standard of Technical Excellence

The art of coronary angiography lies in revealing the most by displaying the least foreshortened coronary artery segment at an angulation that minimizes radiation exposure to the operators and requires the fewest radiographs. However, frames of a coronary segment only depict the stenotic percentage of a luminogram. When analyzing the coronary angiogram in the management of coronary artery disease patients, the cardiologist is not a passive observer. Instead, the cardiologist’s goal is to actively and critically search for both current lesions and potential future lesions in anatomical locations prone to lesion formation (Figure 2.1).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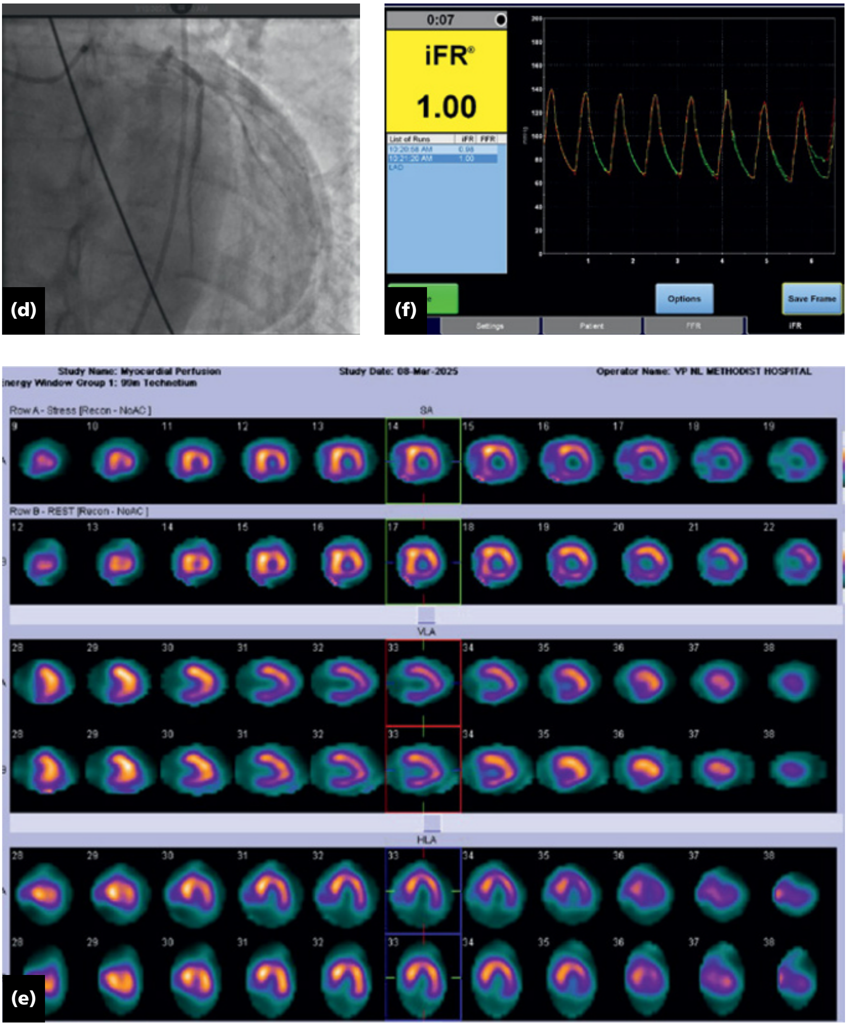
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Figure 2.1 (a) Patient had a moderate lesion in proximal left anterior descending artery. (b) The thallium scan showed not significant ischemia. (c) The instantaneous wave-free ratio (iFR) was normal. Which mechanism confirms that the plaque will not rupture? (See Video 2.1.) (d) Patient had a moderate and possible severe lesion in the mid left anterior descending artery. (e) The thallium scan showed not significant ischemia. (f) The instantaneous wave-free ratio (iFR) was normal. (See Video 2.2.)

Video 2.1. The flow across the lesion is laminar. The meaning of laminar flow is discussed in detail in Chapter 3.

Video 2.2. The patient had slow flow. In this case, the flow dynamics became abnormal before the decrease of distal pressure this was why iFR was negative. The assessment of dynamic flows is discussed in detail in Chapter 3.

GAME PLAY

Moving the Image Intensifier

There are several principles governing the visualization of arteries by adjusting the image intensifier (camera tube) above the patient. The first principle is that the left circumflex (LCX) artery moves with the image intensifier, while the left anterior descending (LAD) artery moves in the opposite direction. For instance, shifting the image intensifier leftward to the left anterior oblique (LAO) view will project the LCX to the left and the LAD to the right (rule 1). Cranial angulation raises the LCX and lowers the LAD, while caudal angulation has the reverse effect. This principle also applies to the diaphragm and the spine (Table 2.1). The second principle is that to straighten a highly tortuous coronary segment, the image intensifier should be positioned at an angle approximately 90° opposite to the current one. This maneuver will reveal the tortuous area as straightened (rule 2). The objective of these adjustments is to view the arterial segment from the most direct (orthogonal) angle, thereby minimizing the effects of projection distortion.

Table 2.1 Movement of vessels and landmarks according to direction of the camera tube

Same direction	Opposite direction
LCX	LAD
Spine	Diagonals
Diaphragm	

GAME PLAN

Sequences of a Coronary Angiogram

There are several ways to initiate a coronary angiogram: the anterior-posterior (AP) view, the right anterior oblique (RAO) view, or the LAO view. However, after obtaining an initial basic view, the subsequent image should either reveal a lesion or confirm the patency of a major branch.

In the left coronary angiogram, there are a few areas to scrutinize:

1. left main (LM)
2. proximal, mid, and distal LAD
3. proximal and distal LCX
4. ostium and proximal obtuse marginal (OM)
5. ostium and proximal diagonals.

The following are the areas of interest in the right coronary angiogram:

1. ostial
2. proximal, mid, and distal right coronary artery (RCA)
3. the right ventricular (RV), posterior descending artery (PDA), posterior lateral branch, and sinus node branches.

Usually, the operator likes to identify the culprit lesion quickly within a specific area of interest.

Real-time Actions

First neutral AP view The preferred initial view is the neutral AP view, as it provides a comprehensive assessment of the LM artery and the proximal segment of the LCX, as well as the precise positioning of the LCX relative to the LAD. In this view, the distal LM, the proximal LAD, and the LCX typically overlap, guiding the selection of the next area to investigate and the subsequent movement of the image intensifier.

RAO and AP caudal view After a global assessment of the LM in the AP view to rule out LM disease, a severe LCX lesion can be quickly confirmed or excluded with a single RAO caudal or AP caudal view. In most cases, with just two views, severe LM and LCX disease can be ruled out, allowing the physician to focus on examining the distal LM and the proximal LAD.

Tips and Tricks

****How to fully expose the LCX: Part 1** Following the initial plain AP view, the goal of the next angulation is to achieve a clear visualization of the LM and the LCX simultaneously. If the LCX is at or below the level of the LAD in the AP view, the next step should be a caudal view or a maneuver that pulls the LCX downward. Deep inspiration further elongates the LCX, preventing foreshortening in the proximal segment and avoiding overlap with the LAD (Figure 2.2).

Two key views are the RAO caudal and the AP caudal. If the proximal LCX is merely foreshortened without significant tortuosity in the AP view, the AP caudal view with deep inspiration will help elongate the heart, depress the diaphragm, and pull the LCX further downward (rule 1). If the proximal LCX is highly tortuous, the RAO caudal view will elongate and straighten the segment (rule 2). With just a second injection, nearly all segments of the LM and LCX can be thoroughly examined.

****How to fully expose the LCX: Part 2** If the LCX appears above the LAD in the plain AP view, the best approach is to elongate the LCX further by pulling it downward in the RAO caudal or AP caudal view. This technique is effective because all cranial angulations will project and foreshorten the LCX further above the LAD. An LAO caudal (spider) view serves as an excellent alternative for visualizing the proximal LCX, although it will be seen against the hazy

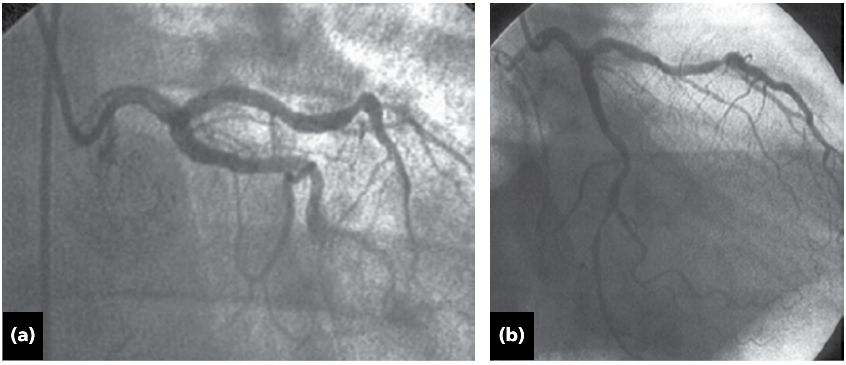

Figure 2.2 Angulation when the LCX is below the LAD. (a) The LCX is below the LAD in this plain AP view. It is also tortuous, so the next view would be the RAO caudal view. (b) In this RAO caudal view, the LCX is well elongated and so fully exposed. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

Table 2.2 How to expose the LCX

Location of LCX	Best next view
If the LCX is below or at the same level as the LAD in the AP view	RAO or AP caudal
If the LCX is above the LAD in the plain AP view	RAO or AP caudal LAO caudal (best alternative view) LAO cranial (best alternative view)

backdrop of the spine. The LAO caudal view provides a clear depiction of the ostial LCX, which is particularly beneficial for guiding wire entry into the LAD, LCX, and the ostium of the first OM branch (Table 2.2).

****How to fully expose the LAD by moving away from the LCX** If, in the AP view, the LCX is clearly below the LAD, the next step is to use any RAO caudal view to pull the LCX downward and eliminate the overlap with the proximal LAD (rule 1). This view can effectively expose the LCX and the LAD simultaneously. If the LCX is at the same level as the LAD, the next angulation should still be any caudal view with deep inspiration to further pull the LCX downward and reveal the proximal LAD hidden beneath it. By this stage, the previously discussed views should have provided sufficient information about the mid and distal segments of the LAD or LCX.

****Two views in the case of left main disease** In a case of LM disease, if it is planned for the patient to have coronary artery bypass surgery (CABG), there is no need to take numerous images with the tip of the catheter inside the LM. The surgical team may require only the mid and distal LAD and the OM for inserting the bypass grafts. Therefore, only two views are needed to show the complete left system (LM, LAD, and LCX) for CABG: (1) AP caudal and (2) AP cranial. If the treatment plan involves percutaneous coronary intervention (PCI), then images of the ostium and the distal bifurcation of the LM must be clear to ensure the successful completion of PCI.

****How to expose the LAD** To straighten a tortuous LAD seen in the RAO caudal view, use the RAO cranial view (rule 2). To resolve LCX overlap on the LAD, use deep inspiration if the LCX is above the LAD; do not use deep inspiration if the LCX is below the LAD. Repeat these maneuvers for the AP cranial view.

****Do we need an LAO cranial view to completely scrutinize the LAD?** A full exposure of the LAD always requires the LAO cranial view to separate the LAD and the diagonals and to expose lesions at the ostium or bifurcations of the diagonals (Figure 2.3). In patients with a prominent abdomen, the AP cranial view with deep inspiration will move the LCX up high above the LAD (rule 1) and the diaphragm down, thus exposing the whole LAD.

****Angulations to separate the LAD from diagonals** In the RAO view, if the first diagonal is above the LAD and overlaps the proximal LAD, a cranial angulation would best separate the LAD and its diagonals. However, the LCX will be moved up and overlap the proximal LAD. If the diagonals are seen below the LAD in the plain RAO view, then a caudal angulation will help to separate the LAD and its diagonal branches (Table 2.3). The best view to visualize the ostial and proximal segment of the diagonals is the LAO cranial view.

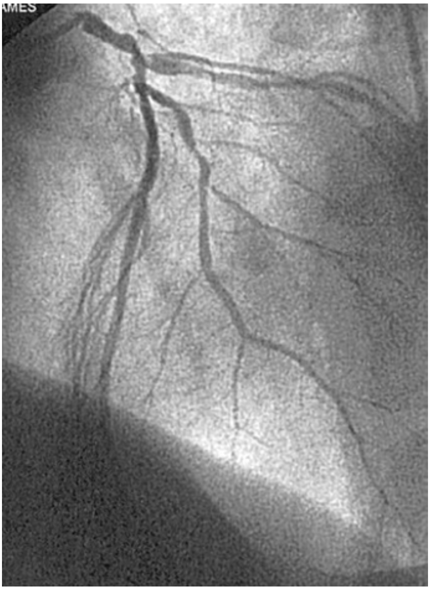

Figure 2.3 Boundaries of the LAO cranial view. A triangle is created by the diaphragm, the spine, and the edge of the intensifier. The LAD should be seated at the top of this triangle for adequate visualization. The diagonals are on the left side and the septal arteries on the right side of the screen. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

Table 2.3 How to expose the LAD and the diagonals

Exposing the LAD	
First AP view	**Next view with deep inspiration**
If the LCX is below the LAD	RAO cranial or AP cranial
If the LCX is the same level	RAO cranial or AP cranial
If the LCX is above the LAD	RAO cranial or AP cranial with deep inspiration
Separating the LAD and the diagonal	
First RAO view	**Next view**
If the first diagonal is above the LAD	RAO cranial view
If the first diagonal is below the LAD	RAO caudal view

LEFT MAIN

Tips and Tricks

****How to expose the LM when the heart is horizontal** The LM artery varies in length from 1 to 10 mm and lacks side branches. It bifurcates into the LAD and LCX arteries (Figure 2.4). In some cases, there is no functional LM or only a very short segment, with the LAD and LCX originating from separate ostia. The LM is assessed through views that highlight

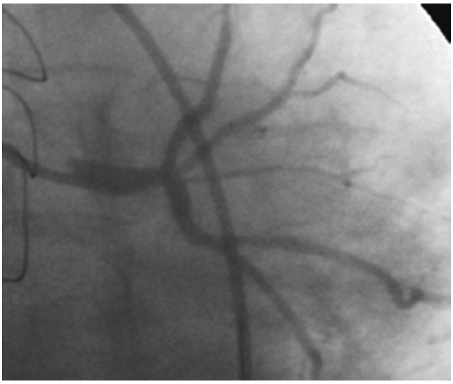

Figure 2.4 LAO caudal view of the LM. In this (spider) view, the LM is seen very clearly at the bifurcation into the LAD and LCX. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

the LAD and LCX. This examination is crucial, as LM lesions are a leading cause of mortality during diagnostic coronary angiography. The primary views for evaluating the LM are the AP and shallow RAO views. If these do not provide a clear image, additional views can be taken based on the heart's position and LM length.

****How to expose the LM when it is long and has a downward direction** As in vertical hearts, the LAO cranial view will yield the optimal visualization of the LM and its bifurcation to the LAD and LCX. An LAO/cranial angulation that is too steep would further foreshorten the LM and, in conjunction with poor inspiration, would produce a hazy background due to diaphragm overlapping (Figure 2.5a–d). If these views cannot clearly delineate the lesions of the LM, other possible views include all combinations of angulation set by an image intensifier (except the AP cranial and lateral views) (Table 2.4).

LEFT ANTERIOR DESCENDING ARTERY

The proximal LAD artery is defined as the segment extending from the ostium to the origin of the first diagonal branch. The distal end of the midsegment is less precisely defined, typically located where the LAD curves downward in the RAO view.

The AP Cranial View

This view is one of the most effective for visualizing the ostial segment, as well as the mid and distal segments of the LAD artery. In patients with a long LM, this view is particularly useful during PCI for proximal or mid-LAD lesions, as it clearly shows the path the wire takes when entering the LAD and advancing forward without interference from the septal or diagonal branches. The AP cranial view can be obtained with deep inspiration if the goal is to elevate the LCX artery above the proximal LAD. However, if the LCX is positioned significantly below the LAD, inspiration is unnecessary, as it will naturally elevate the LCX and cause it to overlap the LAD.

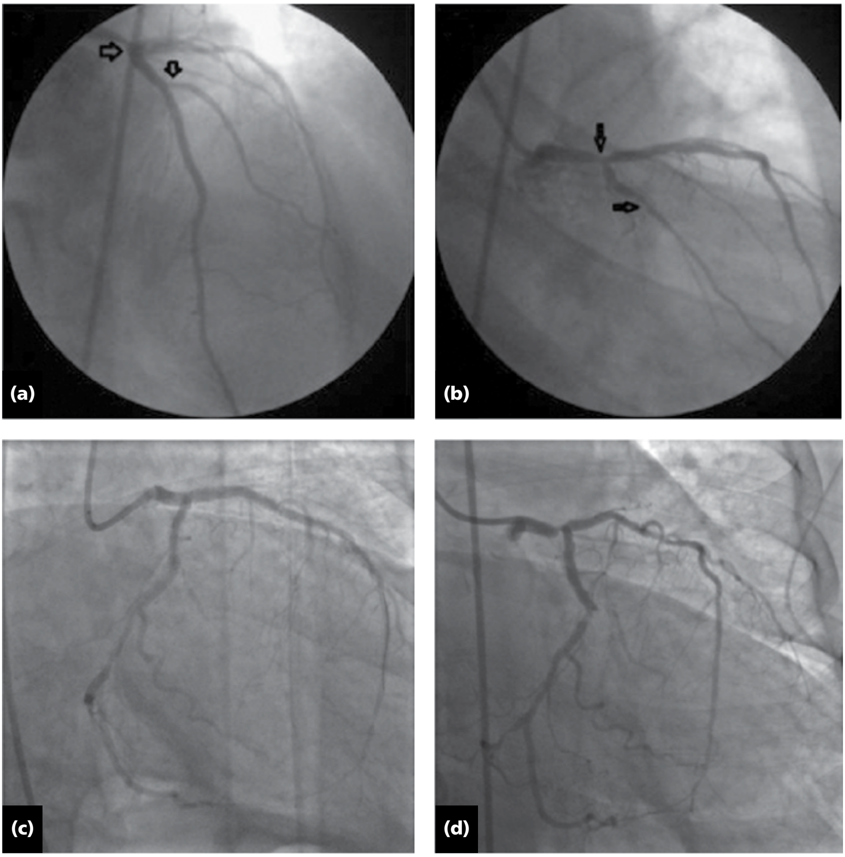

Figure 2.5 (a) In the LAO cranial view, the distal LM and proximal LAD (arrows) are foreshortened. (b) In the RAO caudal view, the distal LM, the proximal LAD, and the LCX are foreshortened. (c) The RAO caudal view, without deep inspiration: No LM lesion was seen because the distal LM lesion is overlapped by the LCX. (d) In this RAO caudal view with deep inspiration, the distal LM lesion is clearly delineated.

Table 2.4 Other possible angles to delineate the left main

Vessel segment	Routine views	Adjunctive views
Ostial	LAO caudal	AP caudal
Body	RAO caudal RAO cranial	AP caudal
Distal	LAO caudal	LAO cranial RAO caudal

The LAO Cranial View

This view provides a clear delineation of the LAD artery from its origin to the apex, along with its relationship to the septal and diagonal branches. The LAD is best visualized when the tip of the guide is positioned within the triangle formed by the spine, diaphragm, and the edge of the intensifier, against a clear lung background (Figure 2.3). To move the spine away from the center, shift the tube to the left, which will in turn move the spine to the left (rule 1). If the result is suboptimal, better definition of the proximal LAD can be achieved by adjusting the steepness of the cranial angulation and having the patient take a deep breath, which lowers the diaphragm and helps make the heart more vertical. This LAO cranial view is useful for visualizing any lesions in the LAD, particularly at the bifurcations with the diagonals and septals. It also helps to track the path of the wire. However, it's important to note that in this view, the proximal LAD is foreshortened, which can limit the accuracy of evaluating the results of angioplasty or stenting in the very proximal LAD.

Confronting the Challenges

How to identify the LAD, diagonals, and septals The LAO cranial view is the best view to identify and confirm the identity of the LAD. (Figure 2.3) In this view, the diagonals are located on the left of the screen, and the septals come out from the right of the LAD. It is almost unthinkable that the LAD has no septals. This view would confirm the identity of a compensatory enlarged diagonal secondary to chronic total occlusion of the LAD. The diagonals would point more to the left side; however, a long LAD in a very dilated left ventricle could have the apex moved toward the left of the screen. Another way to differentiate the septals from the diagonals is that the diagonals move (buckle) during systole, while the septals are straighter and move very little with ventricular contraction. The presence of septals would confirm the identity of the artery as the LAD.

The AP cranial view If the LCX can be fully elevated above the LAD, the AP cranial view will clearly reveal the ostial and proximal segments of the LAD, allowing for a clear visualization of the proximal and midsegments along with their bifurcation. This single view effectively exposes both the mid and distal segments of the LAD, making it a preferred view during PCI. It enables the operator to monitor the position of the guide tip, the movement of devices in the proximal segment, and the positioning of the wire tip in the distal segment.

The lateral view The lateral view can help to pinpoint the location and assess the severity of a lesion at the bifurcation of the LAD and the diagonals. The lateral view is more useful for a diagnostic injection than an interventional procedure because prolonged position of the arm above the head stresses the patients, making them tired and uncomfortable.

The 30° RAO 30° cranial view This view is particularly useful for delineating the ostial, mid-shaft, and distal segments of the LAD artery, with special attention to the proximal LAD–first diagonal branch (LAD-D1) bifurcation. It is valuable for assessing the length of disease in the first and second segments of the LAD to guide stent length selection, as well as for defining the bifurcation anatomy. Increasing the angle of oblique and cranial projection can help better visualize the ostial LAD and LM artery, particularly for stent implantation planning.

Tips and Tricks

****Exposure of the high diagonal** Optimal visualization of the ostium of a high diagonal is often not achieved in the RAO cranial view due to overlap from an elevated LCX artery. In such cases, the operator can use the LAO view with a steep cranial angle (LAO 10°, cranial 40°). However, the spider view with steep caudal angulation is typically the best option for exposing the high diagonal and its origin. This view is also ideal for advancing the wire into the diagonal (Figure 2.4).

****Best view for ostial and proximal LAD in a horizontal heart or short LM** When the heart is horizontal, the LM artery is short, and the proximal LAD artery has a cephalad orientation. In this situation, the LAO caudal view is preferable to the LAO cranial view due to overlapping from the LCX. The positioning of the proximal end of a stent during PCI of the ostial LAD is best visualized in this caudal view (Figure 2.4). However, because the proximal LAD segment is foreshortened in this view, it is not ideal for assessing the complete deployment of a stent or detecting new dissection.

****Best view for ostial and proximal LAD in patients with long LM** If the LM artery is long, the AP cranial view should be the first choice, particularly if the LCX can be elevated above the LAD artery. If the LAD cannot be properly assessed in this view, the next best option is the RAO cranial view. This view provides the clearest visualization of the LM and its bifurcation into the LAD and LCX. Therefore, the optimal views for visualizing the distal LM or ostial LAD are the AP, RAO, or LAO cranial angulations. If these views are insufficient, the next step would be to try the LAO caudal view.

LEFT CIRCUMFLEX ARTERY

The proximal segment of the LCX artery extends from the ostium to the origin of the OM branch. The distal LCX lies beyond this point. When assessing the LCX, a standard RAO caudal view can provide valuable information. However, a shallow angulation has two main limitations: (1) it may foreshorten the proximal segments of the LCX, making it difficult to fully assess the lesion morphology or to evaluate the direction and tortuosity, and (2) the ostial segment may be overlapped and not clearly visible. The proximal region is better visualized with increased caudal angulation. To address the limitations of the RAO shallow caudal view, an AP caudal or LAO caudal view can help clarify issues with the ostial and proximal LCX (Figure 2.2). During this procedure, having the patient take a deep breath can lower the diaphragm, clearing the field and allowing for optimal vessel opacification.

In cases of mid or distal LCX and OM interventions, an RAO caudal view may foreshorten the proximal LCX and mask the severity of the takeoff angle with the LM artery, as well as the tortuosity and potential obstructive lesions in the proximal LCX segment. Often, it is only after unsuccessful advancement of balloons and stents across the proximal segment that the severity of the lesions and tortuosity become apparent. When properly performed, the AP caudal or LAO caudal (spider) view can sharply delineate the ostium and proximal segment of the LCX, allowing the operator to shape the wire and guide it into the artery and proximal segment with minimal difficulty.

RIGHT CORONARY ARTERY

The proximal segment of the RCA extends from the ostium to the first curve. The midsegment begins at the first curve and ends at the second curve and is typically seen as a straight segment in the RAO view. The remaining portion of the artery is the distal segment. The origin of the RCA exhibits considerable variability, ranging from a straight perpendicular takeoff from the aorta to a more caudal direction or even a superior takeoff with a near-180° switchback turn, commonly referred to as the shepherd’s crook configuration. A strong injection into the low right coronary cusp may help visualize the origin of the RCA. If the origin is not visible, it may be anteriorly located, arise from the left sinus of Valsalva, or originate above the sinotubular ridge.

The LAO View

In the LAO projection, the artery appears as a letter "C," while in the RAO position, it resembles a letter "L." To verify the correct alignment of the catheter with the ostial RCA, the best view is the RAO shallow cranial projection. In this view, the catheter tip is seen head-on as a circle (Figure 2.6a). If an angle is formed between the catheter tip and the proximal RCA, it indicates that the catheter is not coaxially aligned (Figure 2.6b). In such cases, friction at the transition angle may reduce the forward force and torquing capacity, hindering the smooth advancement of interventional devices across a tight lesion.

When imaging an ostial lesion, it is helpful to position the catheter just below the coronary ostium and inject a large volume of contrast to clearly define both the extent of the lesion and its precise location on the aortic wall. This view is especially important when planning the deployment of a stent in the ostial RCA. Often, the exact location of the ostium is best visualized in an extreme LAO position (greater than 50°) or an LAO with caudal angulation. To clearly view the ostial segment of the RCA, the optimal view is the LAO caudal projection, which provides excellent visualization of the ostial and proximal segments. For visualizing the distal PDA, the LAO cranial view, coupled with deep inspiration to move the diaphragm out of the field, is ideal for exposing the distal RCA and its bifurcation with the PDA. If further exposure of the distal RCA is needed, an AP cranial view with deep inspiration is the best option.

The RAO View

In the LAO view, the midsegment of the RCA may not be clearly visible due to overlap with the RV branches. The RAO view, however, can separate the midsegment of the RCA from the RV branches (Figure 2.6a). When wiring the RCA, the LAO view helps guide the wire from the catheter into the proximal segment and also aids in selecting the appropriate PDAs in the distal segment. However, due to the presence of marginal branches, the RAO view is better for directing the wire through the midsegment, avoiding the marginal branches, and facilitating smooth advancement to the distal segment.

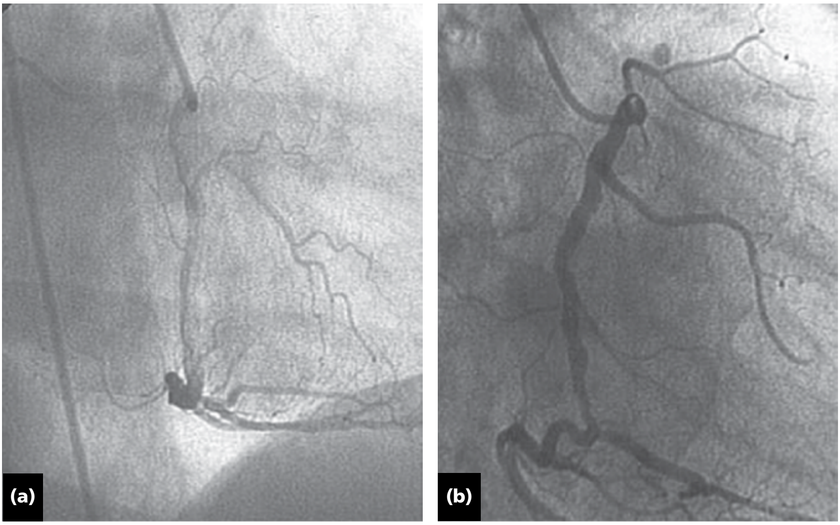

Figure 2.6 (a) RAO view of the RCA. In this view, the guide is truly coaxial, so its tip is seen head-on as a circle. (b) RAO view of an RCA anomaly with the ostium in the anterior position. As the location of the ostium in this case is abnormal, the tip of the guide points to the left. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

SAPHENOUS VEIN GRAFT

The principle of selecting the optimal angle for imaging a venous or arterial graft is to position the view at a 90° angle relative to the direction of the bypass graft. For a saphenous vein graft (SVG) to the OM, if the direction of the SVG is from cranial to caudal (upward to downward), the best view is the RAO caudal view. This view forms a 90° angle with the SVG in the vertical plane and with the OM in the horizontal plane. The ideal view for imaging the ostium or body of the SVG to the LAD artery and diagonals is the LAO view; the LAO cranial view is best for the distal PDA, and the RAO cranial view is optimal for the LAD or diagonals. Detailed discussions of views for SVGs are covered in Chapter 14.

INTERNAL MAMMARY ARTERY

Typically, the left internal mammary artery (LIMA) graft is placed into the LAD artery. Therefore, the primary views for imaging the LAD and LIMA insertion site should be the RAO cranial view (first choice) or the LAO cranial view (second choice). The LIMA insertion site into the LAD can also be clearly visualized in the lateral view, as this view aligns the X-ray beam at a 90° angle to both the distal end of the LIMA graft (in the vertical plane) and the LAD (in the horizontal plane).

Although the LIMA catheter is typically engaged in the AP view to assess the position of the catheter tip relative to the ostium, the best views for this purpose are the 60° LAO or the 45° RAO views. These angulations elongate the aortic arch and separate the subclavian artery, enabling clear identification of the LIMA ostium.

Tips and Tricks

*****Nonselective angiogram of the LIMA** In rare cases where there is difficulty engaging the left and right internal mammary arteries, a nonselective angiogram of the subclavian artery can be helpful. This is done by positioning the catheter tip near the ostium. Complete opacification of the subclavian artery and its branches can be achieved with a 10-mL manual injection while inflating a blood pressure cuff on the ipsilateral arm to 10 mmHg above the systolic pressure [1]. Using a left radial approach for catheter insertion is particularly useful in these situations.

COLLATERALS

In a case of complex PCI or chronic total occlusion in which collaterals need to be visualized in detail, the patient may be given nitroglycerin to dilate all the vessels, and especially the collaterals.

Tips and Tricks

****Optimize the physics of radiology** Use low magnification (13-inch instead of 8-inch) to obtain a broad bird's eye view of the entire coronary vasculature. Avoid panning the table during long cine acquisitions to capture both the arterial and venous phases, including the collateral circulation. To enhance flow in the collaterals and receiving arteries, first inject contrast into the donor artery. Once the collaterals are visualized, inject contrast into the receiving artery. Cine the donor artery for a few seconds after injection to primarily capture the collaterals, minimizing radiation exposure. If the view of the collaterals is suboptimal, increase the cine speed to 30 frames per second (up from the usual 15 frames per second), though this will increase radiation exposure.

****How to lower the amount of contrast** To obtain a good picture of the artery or collaterals, use a large guide. However, if a frequent injection is needed, insert a microcatheter inside the target vessel and inject distally with a few milliliters of contrast.

Confronting the Challenges

Deceiving angiographic views There are angiographic views that minimize the severity of an angulated segment or the severity of a lesion. The most common situation is the RAO caudal view for a lesion in the proximal LCX. This view foreshortens the proximal segment of the LCX, so the ostial lesion of the LCX can be missed and lesions in the proximal segment can be overlooked.

In the RAO cranial or LAO cranial views, a lesion in the distal LM can also be missed; if there is a problem advancing the device or thrombus formation after manipulation of interventional hardware, then the severity of the lesion is better appreciated. In the LAO cranial view, the lesion in the proximal LAD can be missed because it is foreshortened; it can be better seen in the RAO cranial view, AP cranial view, or LAD caudal view (Figure 2.5a–d). During PCI in the RCA, the guide is thought to be coaxial in the LAO view. However, after failure to advance interventional devices or difficulty in withdrawing them, it is found that the guide is not coaxial in the RAO view (Figure 2.6b).

Magnification of artifacts for balloon and stent sizing In the RAO caudal view, the tip of the guide appears smaller than the projected size of the LCX, OM, or RCA because these vessels are positioned posterior to the image intensifier, causing them to appear more enlarged than the tip of the guide. A similar issue arises when measuring the size of the distal LAD artery in the RAO cranial view. In all cases, the image intensifier should be positioned as close to the patient’s chest as possible to minimize distortion.

Missing lesions Coronary angiography, or “luminography,” is well-known to miss severe lesions, particularly short, napkin-ring lesions or short aorto-ostial lesions. This occurs because when the lesion is viewed from an angled projection, it may not be visible, as adjacent contrast-filled vessel segments overlap the short diseased segment, effectively masking the lesion. In the case of an ostial lesion, the tip of a small catheter can be positioned too deeply without causing ventricularization of blood pressure or spill-over contrast into the aorto-ostial region, which can obscure the short, severe ostial lesion. This same issue arises during PCI of an ostial lesion, where it is challenging to properly position the proximal end of the stent, as an angiogram may spill contrast over the ostial area, hindering accurate assessment.

Oversizing the vessel in mid and distal segments In many patients undergoing PCI in the LCX, the reference size of the midsegment of the LCX is measured on the RAO caudal view. In this view, the tip of the guide at the LM ostium is more anterior, while the midsegment of the LCX is more posterior, at the level of the aorta, so the midsegment of the LCX (and the shaft of the guide compared with its tip) is projected bigger on the screen (Figure 2.7a). This is why the size of the LCX as measured by quantitative coronary angiography (QCA) can be quite deceptive. This results in balloon or stent oversizing in PCI of the LCX (Figure 2.7b–d). The same problem occurs with the distal RCA in the AP cranial view and the mid and distal segments of the LAD in the RAO cranial view.

Under-sizing the vessel In the LAO cranial view, the mid-LAD appears smaller because the tip of the guide is positioned posteriorly, while the artery is closer to the image intensifier. As a result, the guide appears larger on the screen, and the LAD appears smaller. Consequently, the balloon or stent may appear smaller than its actual size.

RADIATION

The operator should be cautious when using the X-ray generator to protect him- or herself and the staff from radiation exposure.

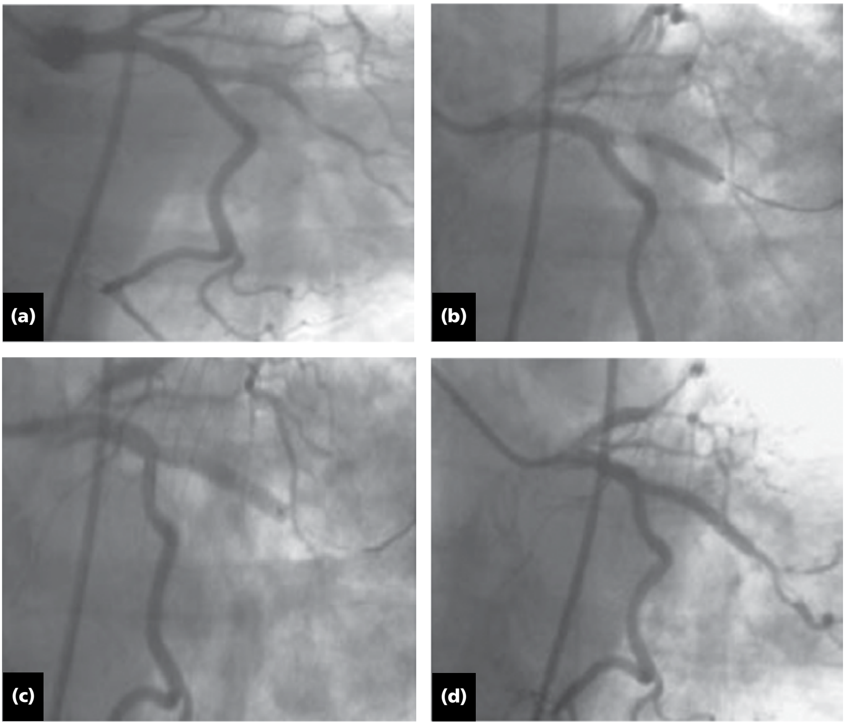

Figure 2.7 False magnification of the LCX. (a) With the size of the guide tip as reference, the OM was measured as 3.8 mm proximally to the lesion and 3.3 mm distally to the lesion. Therefore, a 3.25-mm balloon was selected for predilation. (b) During inflation, an angiogram showed total occlusion of the artery, so the balloon fits well. (c) The body of the guide looked bigger than the tip, so a 3.0-mm stent was selected and deployed. The angiogram during inflation also showed the same size between the proximal segment and the stent size. (d) The post-stenting angiogram showed there was no discrepancy between the diameter of the lumen in the stented area and its proximal segment. The real diameter of the artery was around 3.00 mm, not 3.8 mm as measured with the tip of the guide as reference.

Angulations that Give the Most Radiation

The steep LAO cranial angulation is the view that results in the most radiation exposure to the operator. This is because radiation from the X-ray generator below the table and the X-ray beam is redirected and scattered when hitting the back of the patient. This radiation reflects toward the operator, and there is increased scatter produced by the higher kVp level required for hemiaxial angulation [2]. To obtain adequate X-ray penetration of an obese patient during PCI, the operator should avoid deep angulation, especially caudal angulation. The image magnification should also be lower. This will both reduce radiation exposure to both the patient and operator and limit the amplitude of table panning, thus reducing motion artifacts. Selected suspicious areas are then reimaged with higher magnification.

CORONARY ARTERY ANOMALIES

The most common anomaly is variation of coronary artery origin from the aorta. This is usually of no clinical significance, except in the case of the origin of the LAD from the right sinus or the RCA from the left sinus, which is compressed between the aorta and the pulmonary artery, resulting in ischemia and sudden death [3]. When the LCX originates from the RCA or right sinus, it usually takes a retroaortic course, supplying the lateral wall of the ventricle, and is benign. The left coronary artery (LCA) or RCA can originate from the posterior sinus (very rare) or from the ascending aorta like a bypass graft [4]. Aside from an ectopic origin, their anatomic course is usually normal. These anomalies are considered benign. When the LCA or RCA originates from the opposite sinus, there are four pathways. The rare pathway is the interarterial course; the most common is the septal course. The other two forms are the retroaortic and the anterior course. The interarterial course is the most serious variant because it can cause ischemia, leading to sudden death.

The septal pathway is recognized by the "fish hook" picture in the RAO view of a selective coronary angiogram. This arises because the LM goes down to the septum and then comes up to the epicardium, taking a picture of a fishhook. The LCX would then curve backward and form the "eye" with the LCX as the upper border [5]. In the anterior (pathway), the LM is in front of the pulmonary artery. This pathway is recognized by the "eye," with the LM as the upper border and the LCX as the inferior border (Figure 2.8). Best practice is to obtain a CT angiogram, which can delineate clearly the pathway of coronary anomalies.

Tips and Tricks

****The dots and the eyes** The course of an anomalous coronary artery is suggested by non-selective coronary angiography during the filming of a 30° RAO left ventriculogram. In this visualization, a dot representing the artery seen end-on is noted. The most severe one, the interarterial pathway of an anomalous LM crossing between the aorta and the pulmonary artery, is recognized by the position of the "dot" anterior to the aorta. If the "dot" is behind the aorta, this is the retroaortic benign pathway [5] (Figure 2.8).

A Single Coronary Artery

A single coronary artery is rare. It is defined as an artery that arises from an arterial trunk and supplies blood for the entire myocardium.

Left Circumflex Artery from the Right Sinus

The second most common coronary anomaly is the LCX arising from the proximal RCA. This variant is benign. When the LCX arises from the right coronary cusp or the proximal RCA, it invariably follows a retroactive course, with the LCX passing posteriorly around the aortic root to its normal location. The LAD would be a large artery without the LCX. In a 30° RAO view, the LCX will be seen curving in the posterior area and is seen head-on, as a dot, posterior to the aorta [5] (Figure 2.9). When the LCX originates from the proximal RCA, near to the ostium, if the catheter tip is engaged too deeply, it can pass over the ostium of the anomalous LCX and miss opacifying the LCX.

Right Coronary Artery Anomalies

Anterior position of the ostium If the origin of the RCA is minimally displaced anteriorly, the tip of the right Judkins catheter may not be directed to the right but rather looks foreshortened in the familiar LAO view. Directing the tip to the right in the usual fashion using the LAO view permits easy cannulation of the anteriorly directed RCA orifice. In the RAO view, there would be an angle between the catheter tip and the ostium, with the tip pointing toward the left (see Figure 2.6b).

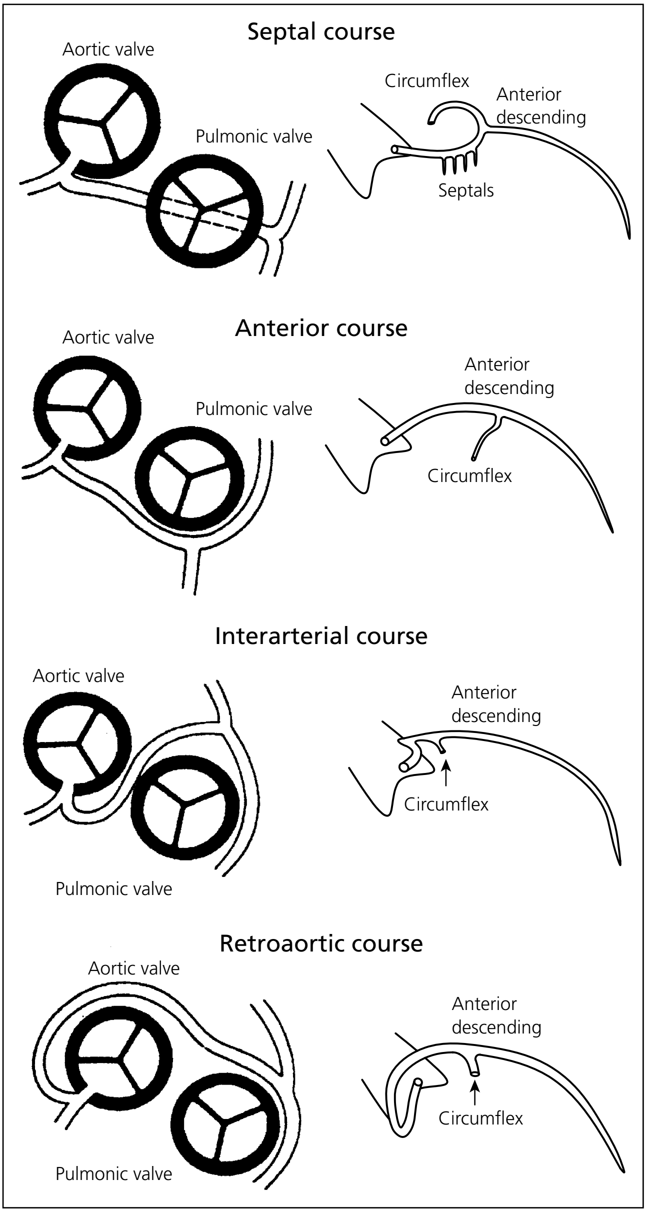
Septal course
Aortic valve
Circumflex
Anterior descending
Pulmonic valve
Septals
Anterior course
Aortic valve
Anterior descending
Pulmonic valve
Circumflex
Interarterial course
Aortic valve
Anterior descending
Circumflex
Pulmonic valve
Retroaortic course
Aortic valve
Anterior descending
Circumflex
Pulmonic valve

Figure 2.8 General view of coronary anomalies. Source: Adapted from [6].

Anomalous origin of the RCA from the left sinus When the RCA arises from the left sinus or from the proximal LM in the RAO view, the RCA will be seen head-on, as a dot anterior to the aorta [5]. Figure 2.10 shows a middle-aged nurse with acute myocardial infarction. Two years later, her son had an angiogram that showed the same anomaly (Figure 2.10).

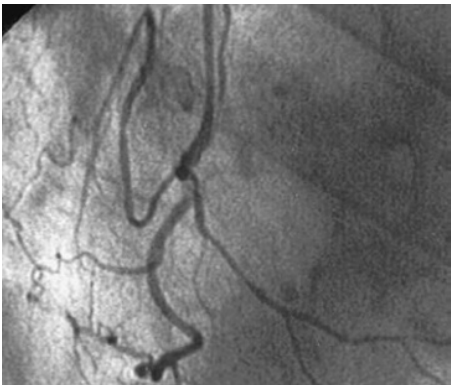

Figure 2.9 In this RAO view, the LCX that originates from the RCA is seen in a retroaortic pathway as the dot is seen behind the aorta and the artery curves posteriorly. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

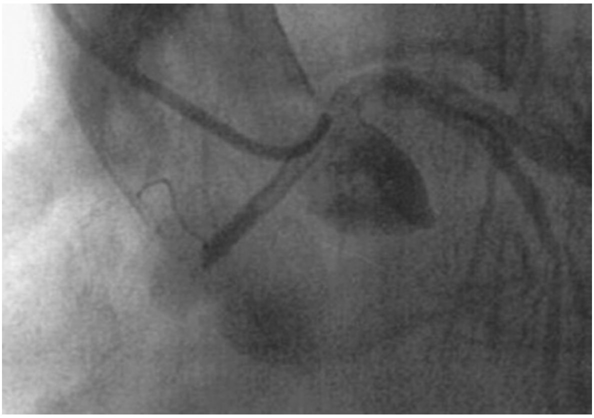

Figure 2.10 In this left coronary injection, an anomalous RCA originating from the left sinus was seen. It was occluded because of acute myocardial infarction. It was then successfully opened. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

RCA from the pulmonary trunk The anomaly in which the RCA originates from the pulmonary trunk. Because of low pulmonary resistance, fully oxygenated blood arriving in the anomalous coronary artery via collaterals from the normal coronary artery is stolen by the pulmonary trunk, resulting in myocardial ischemia. Treatment includes surgical ligation of the RCA and bypass or re-implantation of the RCA [7].

Left Anterior Descending Artery Anomalies

LAD from the RCA or right sinus anterior free wall course The LAD crosses the anterior free wall of the right ventricle in front of the pulmonary artery, then at the mid-septum turns toward the apex. On the 30° RAO view, the LAD will pass to the left and upward before turning to the apex. This coronary anomaly is benign [5].

LAD from the RCA or right sinus septal course The LAD follows an intramuscular course through the septum along the floor of the RV outflow tract. It then emerges at the mid-septum and curves toward the apex. In the RAO view, the LAD appears to move left and downward before turning toward the apex. This type of coronary anomaly is generally considered benign and typically does not cause ischemia [5].

Left Main Coronary Artery Anomalies

The incidence of the LM originating from the right sinus is very low, at only 1.3% [8]. In the RAO view, the artery may take one of several courses: in front of the pulmonary artery (anterior course), through the septum (septal course), between the aorta and pulmonary artery trunk (interarterial course), or behind the aorta (retroaortic course) (see Figure 2.8). Accurate identification of the course is crucial for prognosis, as the interarterial pathway is associated with a higher risk of fatal events.

The septal course The LM follows an intramuscular course through the septum along the floor of the RV outflow tract. It then emerges at the mid-septum, where it bifurcates into the LAD and LCX. Because the artery divides at the mid-septum, the initial portion of the LCX curves above the LM toward the aorta (the normal position of the LAD), forming an elliptical shape with the LM, which resembles an eye with the LM as the inferior border. This configuration is best seen in the 30° RAO view. The LAD is relatively short, with only the mid and distal segments present. One or more septal vessels may also originate from LM. This type of coronary anomaly is generally considered benign and does not typically cause ischemia [5] (Figure 2.11).

The anterior free wall course In the anterior course, the LM crosses the free wall of the right ventricle, in front of the pulmonary artery, and divides into the LAD and LCX at the mid-septum. The LCX would curve back toward the aorta (the position of the normal LAD). On the 30° RAO view, the LCX forms an ellipse ("eye") with the LM on the superior border. There is no myocardial ischemia associated with this coronary anomaly [5].

The retroaortic course In this variation, the LM goes around the aortic root to its normal position on the anterior surface of the heart. It divides into the LAD and LCX at its normal point, so the LAD and LCX have normal length and course. In the RAO view, the LM is seen

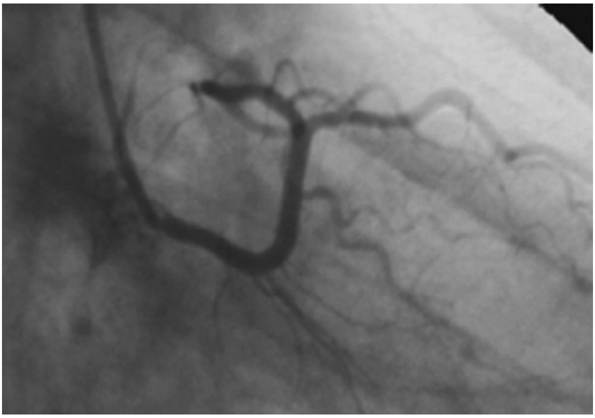

Figure 2.11 The LM from the right sinus by the septal course. The LM forms the inferior border of the eye, while the LCX forms the superior border of the eye. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

head-on, as a circle, posterior to the aorta. This retroaortic dot is diagnostic of a posteriorly coursing artery. There are only rare cases of ischemia reported with this type of anomaly [5].

The interarterial course In this type, the LM courses between the aorta and the pulmonary artery to its normal position on the anterior surface of the heart. In the RAO view, the LM is seen head-on, as a dot, on the anterior aspect of the aorta. The circumflex arises with a caudal orientation. This type of anomaly may be associated with exertional angina, syncope, and sudden death at a young age [5] (Figure 2.12).

Anatomic consideration of the ostial segment Not every anomaly has a wide ostium that the tip of the guide can hook onto or a narrowing at the opening that needs to be stented. There have been several reports that an anomalous RCA from the left coronary artery can leave the aorta in an oblique fashion, so the ostium has a slit-like configuration formed by flaps of aortic and coronary tissues. During exercise, the aorta can expand its part of the flap, further narrowing the slit-like opening and causing ischemia [9].

Mechanism of ischemia due to anomalous pathways If an anomalous artery has to course between the aorta and the pulmonary artery, the expansion of the aorta during exercise can cause narrowing of the midsegment and produce subsequent ischemia. If it happens in young patients, it is an indication for corrective surgery. If the anomaly is found incidentally in asymptomatic elderly patients, surgery is indicated only if objective signs of ischemia can be demonstrated. The reason is that the hardened aorta in older patients no longer expands much, so it does not cause as much exercise-induced ischemia as in young patients. Some anomalous coronary arteries with an intramural course may adhere to the wall of the aorta and can even share a common media with the aorta without intervening adventitia [10].

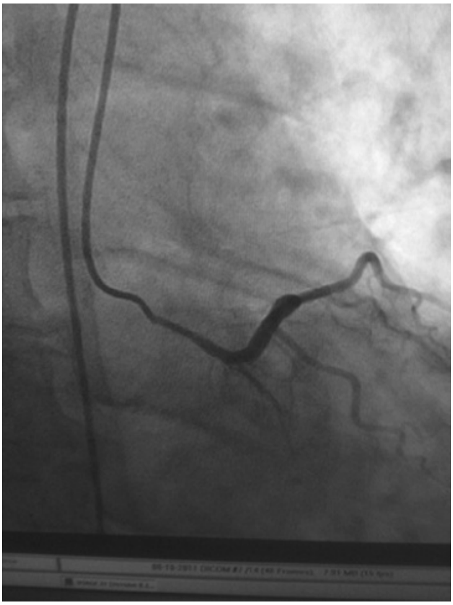

Figure 2.12 LM originating from the right coronary sinus. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St. Mary Medical Center, Hobart, IN, USA.

A new technique of assessing the coronary flow showed reversed (retrograde) flow with persistent spilling of contrast from the coronary artery into the aorta. This new discovery will be discussed in the next chapter.

Left main from the posterior sinus In the AP view, the noncoronary cusp is on the right side and inferior to the left aortic sinus. However, it is seen best in the RAO view, in its posterior location, and identified by the catheter tip in the posterior direction. An injection in the sinus would outline the artery and the posterior wall of the aorta [7].

Angiographic diagnosis of an anomalous RCA arising from the opposite sinus (R-ACAOS) required (1) ostial location within the left sinus of Valsalva, to the left of the anterior aortic commissure, and (2) proximal coursing in front of the anterior commissure of the aortic valve (preaortic) (Figures 2.13 and 2.14). In all patients, the proximal RCA appeared to exit the aorta tangentially (improperly also called "at an acute angle"), and in 14 patients (21%), the RCA ostium originated above the left sinotubular junction (by >5 mm). Two patients had direct origin of the RCA from the proximal LM trunk.

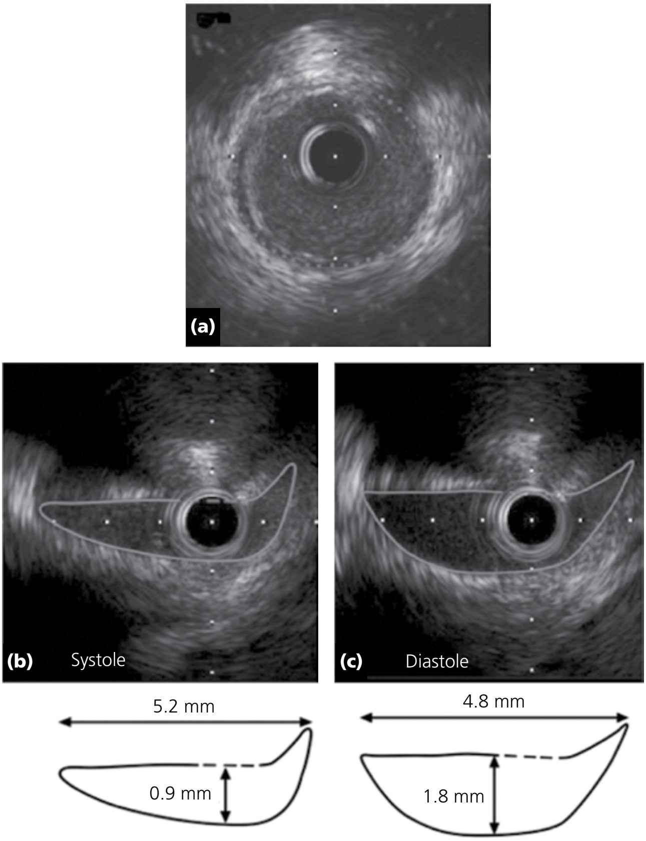

Figure 2.13 Intravascular ultrasonograms in the anomalous RCA arising from the opposite sinus (R-ACAOS). (a) Distal reference cross-sectional area (CSA) is shown. After a solution of saline and blood (4,1 ratio by volume) was infused, images were obtained during (b) systole and (c) diastole. The area and diameters are shown in the lower cartoons. Severity of stenosis is reported as a percentage, computed as the minimal CSA at the point of worst stenosis relative to the distal CSA; in this case, it was about 70%.

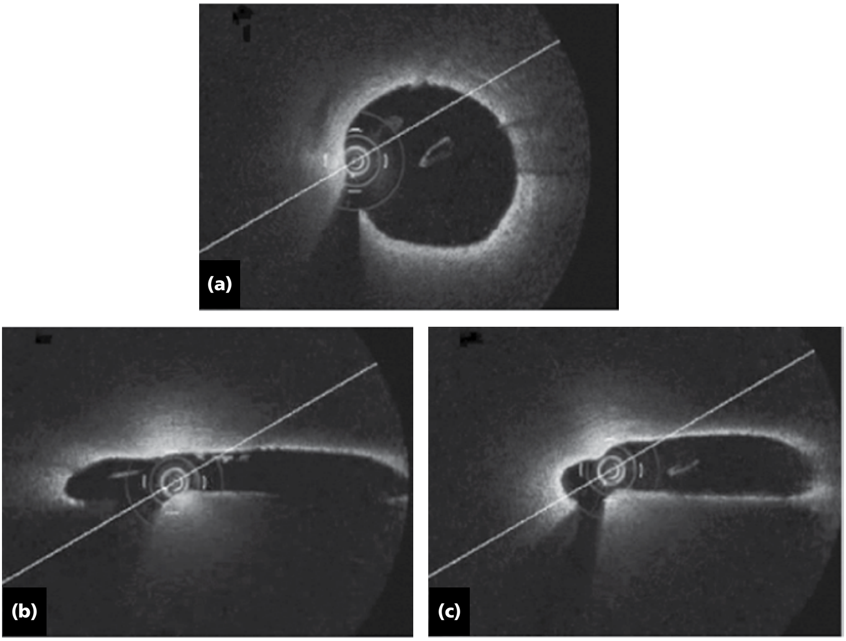

Figure 2.14 Optical coherence tomography (OCT) images. The inner lumen can be crisply imaged with this modality, but only if the operator can advance the guiding catheter selectively enough to eliminate most of the luminal blood, thereby enabling infrared laser imaging. (a) The reference distal cross-sectional area (CSA) is shown (diameters 3.8 × 4.0 mm; CSA 15.42 mm^2) for contrast with (b) the proximal systolic (diameters, 8.7 × 5.3 mm; CSA, 4.6 mm^2; 70% stenosis) and (c) diastolic images (diameters, 6.2 × 10.3 mm; CSA, 6.4 mm^2; 58% stenosis).

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CHAPTER 3

Dynamic Coronary Angiography with Fluid Mechanics and Acoustics Analysis

Thach N. Nguyen, Khiem D. Ngo, Nguyen T. Binh, Loc Vu, Linh N. Luu, Truong Son Dinh, Quynh Nguyen, Hao Thuy Nguyen, Tam QM Tran, Thien T. Truyen, Hoang A. Tien, Duy Chung, and C. Michael Gibson

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CHALLENGES

Scientific Basis for Fluid Mechanics and Acoustics Dynamics in Coronary Flow

In coronary artery disease (CAD) research, the precise initiating risk factor(s) responsible for the onset and progression of coronary lesions remains uncertain. Although common atherogenic factors – such as hypertension, diabetes, hypercholesterolemia, and smoking – systemically affect the whole vasculature, plaque formation occurs selectively in certain arterial segments [1]. Notably, plaques predominantly develop in the coronary arteries, with lower prevalence in the lower extremity arteries and even less frequently in the carotid or renal arteries. Within the coronary circulation, plaque accumulation exhibits a striking pattern, clustering at the distal end of the proximal segment of the left anterior descending artery (LAD), the end of the proximal segment of the left circumflex artery (LCX), and the center of the mid-segment of the right coronary artery (RCA) [2]. What underlies this distinct spatial distribution of plaques? How can we crack the code dictating the mechanisms behind these patterns?

To address these knowledge gaps, our team moved away from biological bench studies or non-invasive imaging, conceptualized the cardiovascular system as a unified network of pumps and pipes, selected fluid mechanics (FM) as the central methodology, and advocated for a paradigm shift from static imaging of luminal stenosis to dynamic assessments of coronary flow [3]. Drawing experiences from fluid mechanic engineering, laminar flow is considered the ideal transportation modality in pipes because it maximizes efficiency and preserves equipment life, while turbulent flow damages the inner surface of pipes and components of pumps [4]. In a similar context, our research protocols investigated potential correlations between laminar flow, turbulent flow, and other arterial phenomena – such as flow collisions, spiraling vortices, and pressure wave reflections from a water hammer phenomenon – with the initiation, presence, absence, preferential site selection, progression or regression of coronary lesions [5].

In patients undergoing multiple coronary angiograms (CAG) over several years or staged percutaneous coronary interventions (PCI), our approach aimed to characterize specific flow disturbances, their transformation, and the relationship between evolving flow dynamics and the emergence of new lesions, preferential lesion sites, or the progression and regression of existing ones over time. To characterize the dynamic properties and temporal variations of coronary flow, we refined the conventional angiographic recording technique to enhance visualization of both normal and pathological flow patterns, along with the mechanistic processes governing lesion initiation, localization, and progression [6]. This advanced imaging approach, termed dynamic coronary angiography, with integration of preliminary artificial intelligence (AI) and machine learning (ML) protocols with acoustic analysis serves as focuses of this chapter.

GAME PLAN

Application of Fluid Mechanics in Coronary Flow Analysis

To substantiate the presence of analogous fluid mechanical abnormalities in both pipe systems and coronary circulation, the authors performed an in-depth comparative analysis of flow phenomena in pipes and coronary arteries, emphasizing their similar underlying mechanisms, lesion distribution, boundary conditions, and the dynamics of pressure wave reflections. These analyses considered the unique constraints of the relatively short, flexible coronary arteries compared to the long and rigid domestic pipes or industrial pipelines. As further analysis and review progressed, the authors identified the water hammer phenomenon as a plausible mechanism responsible for most intimal injuries [7].

APPLICATION OF ACOUSTICS IN THE INVESTIGATION OF CORONARY FLOW DYNAMICS

Following the establishment of boundary conditions and the characterization of flow dynamics in coronary arteries modeled as tubular structures, the investigations were shifted toward the dynamics of the water hammer event in coronary arteries [7]. To analyze this phenomenon, acoustic principles were utilized to evaluate the retrograde pressure wave propagating at nearly the speed of sound in both pipe systems and coronary arteries.

At first, *in vitro* experiments involved sound waves traveling through a tubular structure, filled with air particles which remained undisturbed at baseline and occupied in their equilibrium positions, distributed uniformly in a random configuration.

When a pressure wave propagated through, the movement of the air particles adhered to fundamental acoustic principle. Rather than exerting force to drive or compress the entire column of particles, the wave only induced displacement of the particles from their equilibrium positions. This displacement occurred either axially, characterized by vertical oscillation at a fixed point, or longitudinally, involving oscillation along the length of the pipe [8] (Figure 3.1). The particles were concentrated in high density in the zone of compression, alternate with areas of moderate density (rarefaction). The zones of compression with maximal oscillations depicted high pressure and turbulence. The zone of rarefaction with minimal oscillation had lower pressure fluctuation so less turbulence. In the segments between compression and rarefaction, there was no turbulence.

Within this framework, analogous acoustic phenomena were observed in coronary angiography, as evidenced by patterns of contrast distribution. Specifically, after the injected contrast filled the target coronary artery, distinct localized regions of remnant contrast concentration emerged during contrast clearance: high-density contrast zones (compression zones, classified as antinodes), moderate-density contrast zones (rarefaction zones, also categorized as antinodes), and areas with minimal contrast retention (nodes). These compression and rarefaction zones in coronary arteries, resembling pressure variations in Figure 3.1, suggest that localized pressure surges may contribute to intimal injury.

A similar pattern of air bubble pockets within compression and rarefaction zones leading to cavitation has been reported in oil pipeline transport, where pressure waves propagate through the system [9]. Furthermore, cultured cells clustered in compression and rarefaction patterns has been documented in culture tubes exposed to pressure waves [10]. The spatial distribution of these antinodes and nodes, along with their correlation to corresponding lesions, is presented in Figure 3.2.

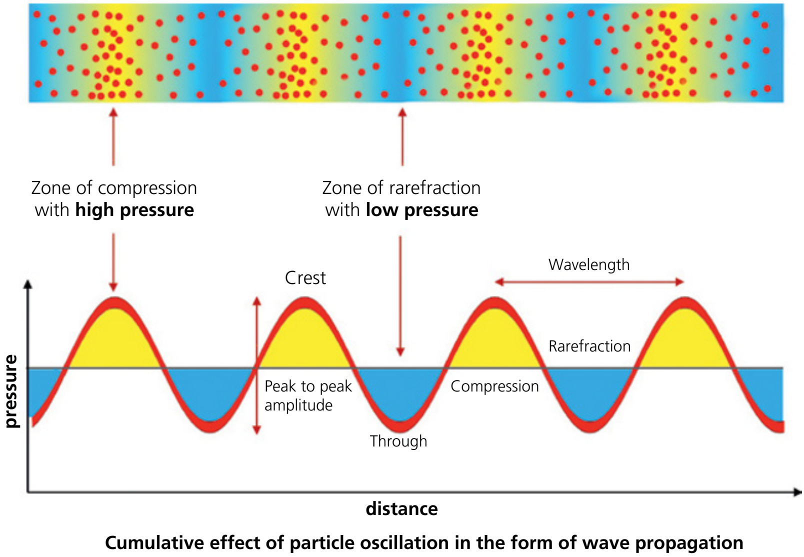
Zone of compression
with **high pressure**
Zone of rarefaction
with **low pressure**
Wavelength
Crest
Rarefaction
pressure
Peak to peak
amplitude
Compression
Through
distance
Cumulative effect of particle oscillation in the form of wave propagation

Figure 3.1 In an experiment in a tube, when a pressure wave passed by, the movement of air particles followed the acoustics principles. The particles were concentrated in high density in the zone of compression, alternate with areas of moderate density (rarefaction). The zones of compression depicted maximal oscillations with high pressure and turbulence. The zone of rarefaction had minimal oscillation with lower pressure fluctuation so less turbulence.

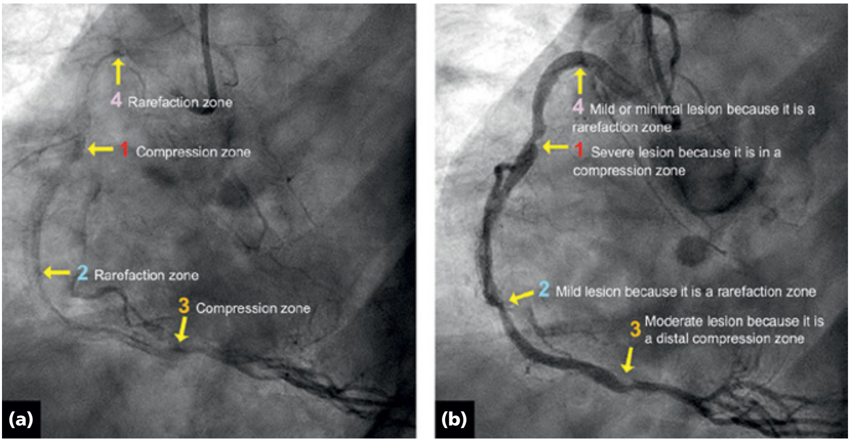
4 Rarefaction zone
1 Compression zone
2 Rarefaction zone
3 Compression zone
(a)
4 Mild or minimal lesion because it is a rarefaction zone
1 Severe lesion because it is in a compression zone
2 Mild lesion because it is a rarefaction zone
3 Moderate lesion because it is a distal compression zone
(b)

Figure 3.2 a–b. This is the angiogram of the right coronary artery at the end of diastole with all the contrast almost flushed out. Pockets of high contrast concentration persist. These stagnation zones represent the high or moderate concentration of contrast particles and correspond to zones of compression and rarefaction at the location of antinodes. The antinodes at #4 defines the distal end of the coronary artery as a tube based on the retrograde direction of the pressure wave. The antinodes at #1, #3 depicts the zones of compression while #2 depicts the zone of rarefaction. In between these antinodes, these coronary segments are the location of nodes which are clear of lesions because possibly there is no clash with the pressure wave.

CRITICAL THINKING

Analysis of the Mechanism of Damage from Fluid Mechanics and Acoustics Perspectives

Within the framework of coronary artery dynamics, antegrade blood flow is dominant during diastole, governed by fluid mechanics. At location #1 in Figure 3.2, flow deceleration occurs due to the transition from diastole to systole, while at location #2, flow acceleration is observed as diastole resumes. At time zero – marking the onset of systole – a retrograde pressure wave, generated by a water hammer effect, propagates backward from the distal end of the coronary artery. This constitutes an acoustic phenomenon. The retrograde wave elicits distinct hemodynamic responses at locations #1 and #2, shaped by their respective baseline flow velocities. These responses reflect the interaction between fluid dynamic processes and acoustic wave propagation.

At location #1, where forward momentum is diminished, the incoming pressure surge leads to a pronounced rise in local pressure. The reduced kinetic energy at this site renders the flow more susceptible to reversal or oscillation under the influence of the backward pressure gradient. This disturbance amplifies shear forces and exacerbates turbulence, particularly in near-wall regions where velocity gradients become steeper. Particle trajectories destabilize, exhibiting retrograde displacement or transient stagnation during the passage of the wave.

Conversely, at location #2, where the flow is regaining speed, the retrograde wave still elevates pressure but exerts a comparatively milder effect due to the greater forward kinetic energy. Although a brief deceleration occurs as the wavefront interacts with the advancing flow, the overall direction of motion is typically preserved. Turbulence intensifies modestly as the forward flow undergoes compression, causing particle paths to deflect without full reversal. The compliant nature of the arterial wall further modulates these dynamics, as the pressure spike causes temporary vessel distension, enabling short-term energy absorption and partial wave attenuation. In general, this is the result of an interaction between a fluid mechanics process with an acoustic phenomenon.

INVASIVE CARDIOLOGY APPLICATION

To Codify the Coronary Lesions

When a retrograde pressure wave propagates through coronary arteries under the acoustic principle, the pressure wave generates alternating regions of compression and rarefaction of contrast particles. At compression points (e.g., locations #1 and #3), there is a high concentration of contrast, whereas at rarefaction points (e.g., locations #2 and #4), the contrast concentration is less dense (Figure 3.2a).

At location #1 with compression, corresponding to a pressure crest, the low-pressure antegrade flow during diastole is rapidly overtaken by a high-pressure surge during systole, producing a pronounced pressure peak. This abrupt surge induces disruption of the endothelial barrier of the intima and increases the likelihood of severe damage leading to more severe lesions, plaque rupture, and the onset of acute coronary syndrome (ACS) (Figure 3.2a, b)

In contrast, at location #2, where rarefaction creates a pressure trough, the transition from high-pressure systolic flow to lower-pressure diastolic flow leads to a pressure decrease. Unlike location #1, the absence of significant pressure surges at location #2 results in minimal turbulence, reducing intimal damage. Consequently, lesions in these regions are less severe, and the risk of triggering ACS is comparatively lower. Moreover, in

(*Continued*)

the very short artery, the limited distance constrains the pressure surge, preventing the buildup of sufficient pressure momentum (Figure 3.3a–b).

With a low-pressure surge because the pressure is low at the end of an artery, lesions at location #3 develop gradually due to the progressive deposition of atherogenic particles. In the segment between these lesion or nodes, where pressure fluctuations and particle motion are minimal, the lack of significant dynamic stress inhibits lesion formation and progression, consequently, these segments exhibit minimal or no lesions.

In summary, conceptualizing the coronary artery as a tubular structure subject to a retrograde pressure wave generated by a water hammer event and governed by acoustic principles, the distal end of the coronary artery (location #3) functions as a proximal closed end, representing a compression zone. In contrast, location #4 marks the interface between coronary retrograde pressure wave and aortic root flow, serving as the distal open end – characterized as a rarefaction zone. Location #1 corresponds to the site where the retrograde pressure wave encounters a resistance point with preexisting flow deceleration, thereby constituting another compression zone. Location #2, by contrast, represents the point where the retrograde wave meets a region of increasing forward velocity and greater inertial stability, thus forming a rarefaction zone. Based on the spatial distribution of these compression or rarefaction zones, an acoustic coronary map can be constructed in identifying all possible current lesions while the presence and duration of contrast concentration in these zones could serve as surrogate markers of pressure surge in predicting future lesions. (Figure 3.3 and Table 3.1) [7].

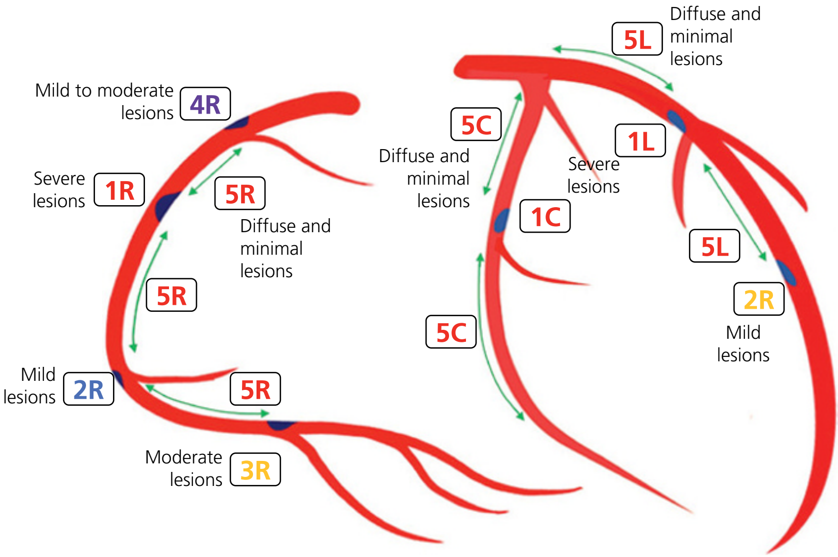

Figure 3.3 **Coronary Acoustic Map**. In the coronary arteries, the most severe lesion happens at the compression antinodes (location #1) or moderate lesion at #3, while mild lesion happens at the rarefaction antinodes (2 and 4). Conversely, the segments in between the antinodes 5R, 5C and 5L have diffused minimal or no lesion due to minimal pressure fluctuations. (R = right coronary artery, C= left circumflex artery, L= left anterior descending artery).

Table 3.1 **Codified coronary lesions based on location and mechanism**

Label	Locations	Incidence	Severity	Growth	
#1R #1L #1C	Mid RCA, end of proximal LAD and LCX	High	High	Fast growth High risk of rupture	Collision at the transition from diastole to systole with the retrograde systolic pressure wave against the low diastolic pressure antegrade flow
#2R #2L	Beginning of distal RCA, LAD	Low	Mild	Slow growth Low risk of rupture	Collision at the transition from systole to diastole with the systolic pressure de-escalates to low diastolic pressure so there is less turbulence
#3R #3L #3C	Distal RCA, distal LAD	Low	Moderate	Slow growth Low risk of rupture	Collision at the location starting the water hammer shock Retrograde recirculating flow in ostial PDA
#4R #4L #4C	Proximal RCA, possible ostial LAD or LCX	Rare	Mild	Slow growth Low risk of rupture	Collision at the end of the pressure wave: Rarefaction zone so turbulence is low
5R 5L 5C	Mid RCA, proximal LAD and LCX	Common	Diffuse mild	Mildly calcified	Prolonged stagnant flow with slow speed (boundary layers)

RCA: right coronary artery, LAD: left anterior descending artery, LCX: left circumflex artery, OM: obtuse marginal branch, PDA: Posterior descending artery

GAME PLAN

New Technique of Dynamic Coronary Angiography

In the new dynamic angiographic technique, the aim is to image distinctly and identify accurately the different types of flows, e.g., laminar, antegrade and retrograde flow, boundary layer, the length of the arterial phase and the arterial phenomena such as vortex formation, retrograde pressure wave from water hammer shock or disorganized (turbulent) flow, etc. This new recording and reviewing method are described in detail in prior publications and are summarized below [6].

Injection of Contrast and Recording of Images

At first, the contrast medium is injected until the index coronary artery is completely opacified. When some contrast in black color is seen ejected back from the coronary ostium into the aorta, the manual injection stops (Figure 3.4a). As the blood in white color enters the vessel, the shape, movements, directions, and interactions of the blood flow could be clearly observed and easily identified against a background of black contrast (Figure 3.4b–c). The CAG is recorded from the beginning of injection until all the contrast disappears from the distal arterial vasculature (i.e., arterial phase) as the blood finishes displacing the contrast (Figure 3.4d), and the recording ends after the contrast is flushed out of the coronary veins (i.e., venous phase).

During the recording, the camera is positioned at an angle that could record the index artery and vein in their full length, with all the images completely visible within the screen, at 15 images per second (sec) or 0.067 sec or 67 milliseconds (msec) interval between consecutive images. The views should be selected as all movements of the blood (and contrast) could be sharply observed in a clean background of the lungs. The selected angles circumvented superimposing the arteriograms or venograms on the bony structures of the spine or on the myocardium filled with contrast at the end of the arterial phase and during the venous phase. The CAGs were saved and stored in the EPIC Electronic Health Record (EHR) System (Epic Systems Corporation, Verona, WI).

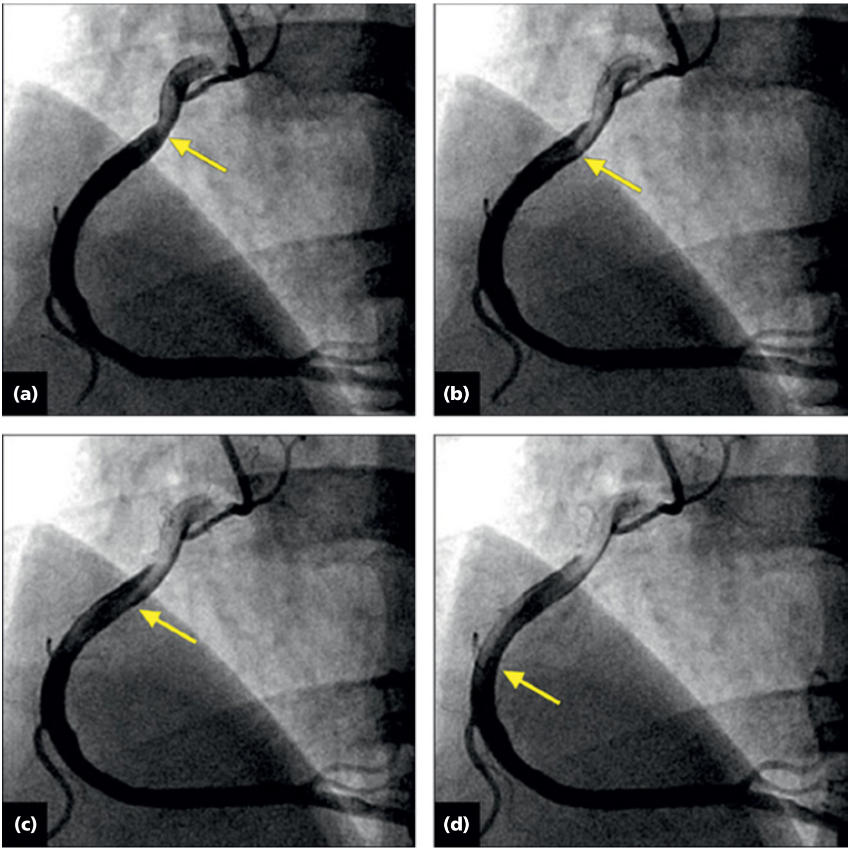

Figure 3.4 a–d. These four coronary images are of consecutive sequence. (a) This is the angiogram of the right coronary artery (RCA), which is filled with contrast in black. (b) The blood (in white) is seen well organized with sharp border and a pointed tip, curving along the apex (yellow arrow). (c-d) The blood (in white) is seen following the apex of the curves (yellow arrow). This is the laminar flow following the curves in a helical fashion.

Review Protocol of a Dynamic Coronary Angiogram

Reviewers access the data in the Picture Archiving and Communication System (PACS), which is integrated with the EHR, retrieve the entire CAG, and select the series to be examined. While playing the CAG on cine mode, the reviewers made a "right" click on the computer mouse, chose the Key Image option, and used the "Up and Down" arrow keys to move the images. The reviewers could view the images one by one as well as scroll them down at desired speed. The CAGs are de-identified by removing the demographic information, adding a new code number, and saved in a Microsoft® PowerPoint file (Microsoft Corporation, Redmond, WA, USA). Consequently, the images of CAGs could be reviewed multiple times in hard copy at desired speed; without the need of re-accessing the security and firewall-protected EHR [6]. With the high-speed recording of 0.067 seconds interval between images, many new features were discovered through thorough scrutiny of one, two or three static images on the PowerPoint slides. This practical approach allows complete visualization of the dynamics of flow within the arterial lumen that would not have been able to be discovered at current reviewing speed of cine-angiography on laptop or desktop.

ANGIOGRAPHIC VIEWS

BEST PLAYERS

Criteria of EXCELLENCE

In the new dynamic angiographic recording, all detailed movements of the blood (and contrast) need to be captured distinctly and identified accurately on a clean background of the lungs. The selected angles of the projector circumvent superimposing the arteriograms or venograms on the bony structures of the spine or the myocardium filled with contrast at the end of the arterial phase and during the venous phase. The goals are to image, detect and visualize well the white blood flow on a black contrast background and the listed codified lesions and segments of the coronary acoustic map (Figure 3.4). The criteria of excellence when recording the angiogram are listed in Table 3.2.

Left Main Artery

The left main artery (LM) needs to be delineated in full length so the entry flow from the aortic root and the hydraulic phenomena at the mid-segment and the distal bifurcation can be captured. The best views for the ostial LM and mid-segment are (1) the anteroposterior (AP) caudal views (Figure 3.5a–b) and (2) the left anterior oblique (LAO) caudal (spider view). The flows in the LM could clarify the mechanism of entry flow and angle of attack, which injures the intima at a specific location in the LM, starts a lesion, promotes its growth (at the upper or lower border), or ruptures its cover and precipitates acute coronary syndrome.

Table 3.2 Criteria of angiographic excellence

1. **The left main (LM**) needs to be delineated on its entire length from the ostium to the bifurcation in order to capture all the fluid mechanic (FM) mechanisms of entry flow and angle of attacks which affect the formation of lesions at the upper versus lower border, at the middle or distal LM.
2. **The transition** from the LM to the left anterior descending (LAD) and left circumflex (LCX) arteries has to be delineated so that all the mechanisms affecting bifurcated flows and lesions (laminar or turbulent, at the center or the side, at the entry and exit shoulder of the LAD and LCX can be identified, documented and tabulated.
3. **The proximal segments of the LAD and LCX** must be seen clearly, mainly the outer curve of the proximal LCX and LAD with a boundary layer and its recirculating flow where plaques are commonly formed (segments **5L and 5C**). The end of the proximal segment is a very important because most lesions (**1L and 1C**) develop here.
4. **The bifurcations of the LAD with the diagonal and the LCX with the obtuse marginal** need to be delineated well to detect the antegrade or retrograde flow or collision causing LAD and LCX lesions proximal or distal to the bifurcation angle. (**lesions 1L and 1C**)
5. **The mid-segment** of the right coronary artery (RCA) is where most lesions are located (**lesion 1R**). Here is the location of a collision between antegrade diastolic flow with the retrograde pressure wave generated by a water hammer shock, triggering atherosclerosis
6. **The distal segment of the RCA** at the junction between the RCA and posterior descending artery (PDA) and posterior lateral branch (PLB), where the majority of distal and slow growth lesions (**lesions 2R ad 3R**) are located.
7. **The junction** between the proximal and mid-segment of the RCA (or any curved segment) where lesion could develop due to repeated hinge motion

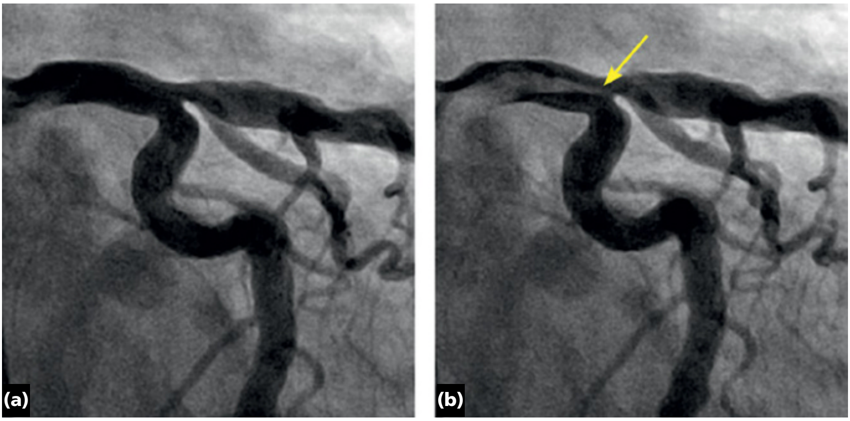

Figure 3.5 a–b. The antero-posterior (AP) caudal views. These two images are not in consecutive sequence. (a) The left main coronary artery (LM) was seen well with the bifurcation of the left anterior descending artery (LAD) and left circumflex (LCX). There was a narrowing at the ostium of the LAD. (b) The blood in white color was seen moving in a laminar pattern with a pointed tip (arrow). The boundary layers on both sides of the laminar flow were well delineated. Even though the stenosis was severe by measuring the minimum lumen area (MLA) >75%), the fractional flow reserve was negative. This patient has been stable for the last five years. The mechanism of clinical stability was most likely due to the presence of laminar flow across the lesion and the treatment with beta-blockers and statins.

Dynamic of flow damage to the left main When investigating the flow of the LM, there are questions to be answered regarding the types of flow and their effects at the LM, its bifurcation and the proximal LAD and LCX. The questions are: Is the LM short or long? How is the flow in the LM – laminar or turbulent? Where does the entry flow hit – the inferior or the superior border of the LM? When does the turbulent flow from the aorta to the LM become laminar? (Figure 3.6a–d)

Height of the coronary sinus Is the height of the coronary sinus above or below average? If the height of the coronary sinus is above average, retrograde flow from the ascending aorta to the LM will hit the inferior border of the LM so the lesion will form on the superior border of the LM. If the height of the coronary sinus is below average, the lesion will form on the inferior border of the LM. The reason is that retrograde flow from the ascending aorta to the LM will hit the aortic valve before making a U turn up and striking the superior border of the LM (Figure 3.7).

Left Anterior Descending Artery

Dynamic of flow damage In the left anterior descending artery (LAD), the flow to be seen is at the ostium, the outer curve or the upper border of the proximal segment, which is a preferred location of plaques (**lesion 4L**), an area with low shear stress and at the distal end of the proximal segment (**lesion 1L)**. The best views for the ostial and mid- LAD are:

1. The left anterior oblique caudal (spider view) for the ostium (Figure 3.8)
2. The left anterior-oblique cranial views for the proximal segment (Figure 3.9)
3. The anteroposterior cranial views for the proximal and mid-segment (Figure 3.10)

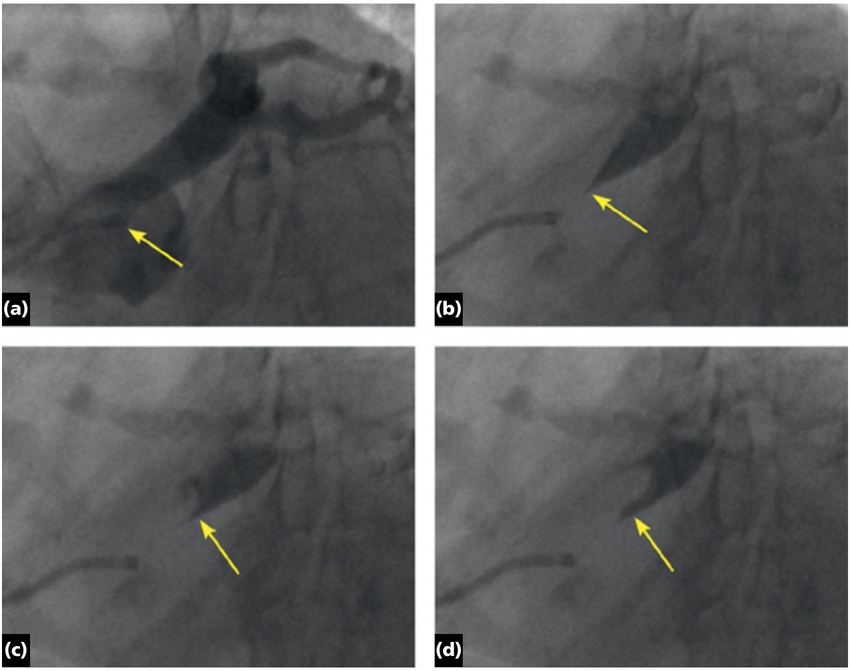

Figure 3.6 a–d. Entry Flow and Angle of Attack. These images are of no consecutive sequence. (a) The left main coronary artery (LM) was seen well in its proximal and mid segments. The tip of the catheter was outside the LM (arrow). (b) Because the LM was large while the left anterior descending artery was much smaller, the contrast formed a thick boundary layer, which started at the mid-segment of the LM and became thicker at the distal end of the LM, in the form of a triangle. (arrow). (c) At the beginning of diastole, the blood in white moved in and first hit the boundary layer at its base. (arrow). (d) Then the blood in white began to move up toward the center of the flow. (arrow) Pictures C and D were important because the blood first hit the lower border of the LM. If there was a lesion at mid-LM, the jet of blood would have hit the base of the plaque and ruptured its cover at the junction between the cover and the normal intima. This is the mechanism of injury at a specific location of the LM based on the angle of attack.

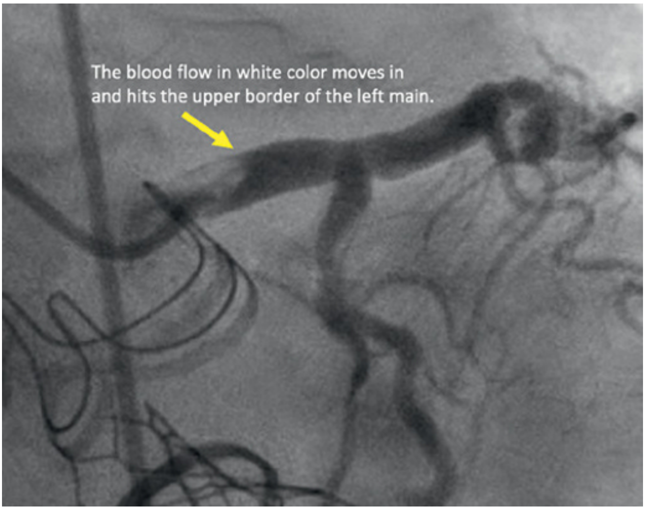
The blood flow in white color moves in
and hits the upper border of the left main.

Figure 3.7 This is the image of the left main (LM) coronary artery. The upper and lower borders of the LM were smooth. A thick streak of blood in white color moved in and hit the upper border of the left main artery.

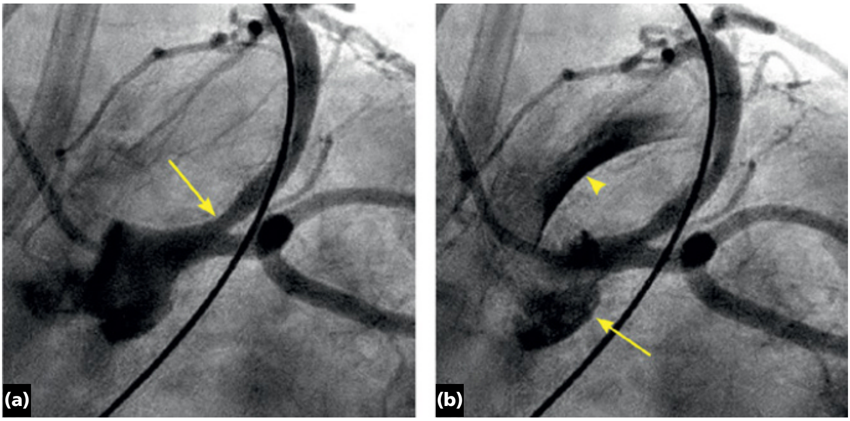

Figure 3.8 a–b. Timing systole and diastole by the Left Anterior Oblique (LAO) caudal (spider) view. These are the two consecutive images of the left main (LM) at the spider view. They are separated by 0.06 seconds (recorded at 15 frames per second). (a) In this view, the ostium of the left anterior descending (LAD) artery is seen well, so the flow through it would be imaged well. (arrow). (b) In this view, the contrast in black color could be seen ejected from the aortic root and coronary sinus into the ascending aorta, (arrow) and the black contrast at the ascending aorta (arrowhead). This is the beginning of systole. These features help timing and differentiating the flow in the coronary artery during systole and diastole.

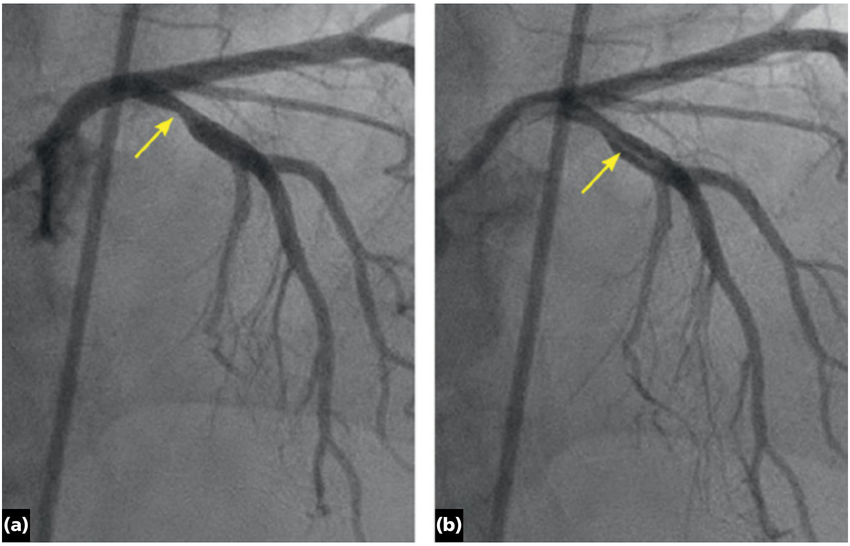

Figure 3.9 a–b. Laminar Flow across a lesion at the left anterior oblique (LAO) cranial view which is important for the presence of antegrade laminar flow or turbulent retrograde flow. (a) In this anterior-posterior (AP) cranial view, the proximal segment of the left anterior descending (LAD) artery was filled with contrast. There was a moderate lesion (arrow). (b) In this view, the blood in white was seen crossing the stenotic segment in laminar flow (arrow) over a background of black contrast. Under the protective effect of laminar flow, the lesion stayed stable, not progressing to acute coronary syndrome while the patient was on optimal dose of beta-blockers and statin

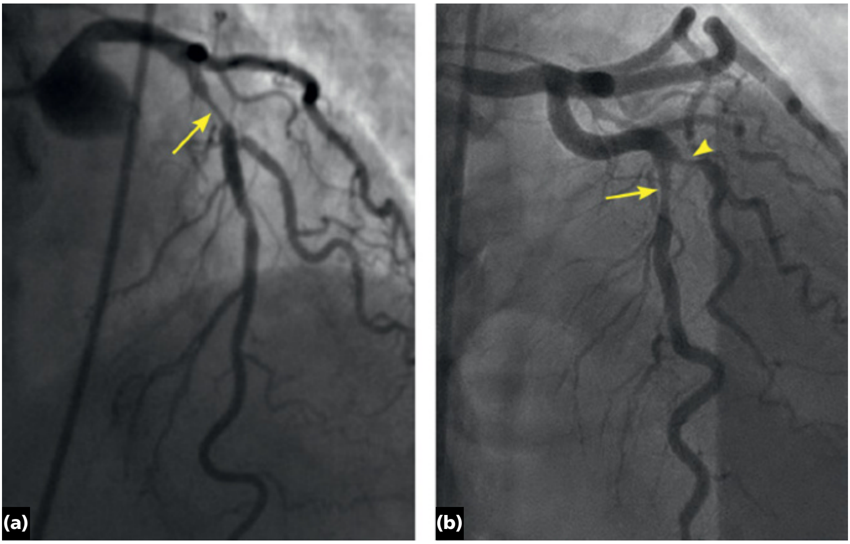

Figure 3.10 a–b. **Lesion in the proximal and mid left anterior descending artery (LAD) by the antero-posterior (AP) cranial view.** This view is essential for searching for antegrade laminar or turbulent retrograde flow. (a) There is a critical narrowing at the proximal segment of the LAD, proximal to the origin of a moderate size diagonal (arrow). In our research protocol, for a lesion at this location, we would ask: Why and how did the lesion form at this location of the proximal LAD, proximal to the ostium of the diagonal and the main branch? (and why not at other locations?) Which fluid mechanics mechanism(s) was (were) responsible for forming lesions at this location? Why does the lesion have a rat tail configuration (gradually severe from proximal to distal)?. (b) This picture shows a critical narrowing at the beginning of the mid-segment of the LAD (arrow) and the ostium of the moderate-size diagonal (arrowhead).

Left Circumflex Artery

Dynamic of flow damage In the left circumflex artery (LCX), the flow to be searched is at the ostium, the outer curve opposite to the carina, the mid-segment, or the obtuse marginal (OM) branches. The best views for the ostial and mid-segment LCX are the AP caudal view or the right anterior oblique (RAO) caudal, which shows well the ostium and proximal segment of the LCX **(lesion 1C)** and the branches of the OM. The AP caudal view is used when the proximal segment of the LCX is not tortuous. The right anterior oblique (RAO) caudal is better when the proximal segment is curved or tortuous. (Figure 3.11a–i)

Right Coronary Artery

Dynamic of flow damage In the right coronary artery (RCA), the flows to be searched are listed in Table 3.3.

The best view for the flow at the ostial, proximal, and mid-RCA is the LAO caudal view (spider view). (Figure 3.12a) The LAO cranial view is the best view for flow of the distal RCA and bifurcation with the posterior descending artery and posterior lateral branch (Figure 3.12b).

Both Figures 3.13a–b showed severe lesion in the mid RCA but with different morphologies. At first glance, the two coronary angiographic images appear similar; however, a closer examination reveals critical differences. The lesion in Figure 3.13a exhibits a rat-tail configuration, with severity progressively increasing from proximal to distal direction. In contrast, the lesion in

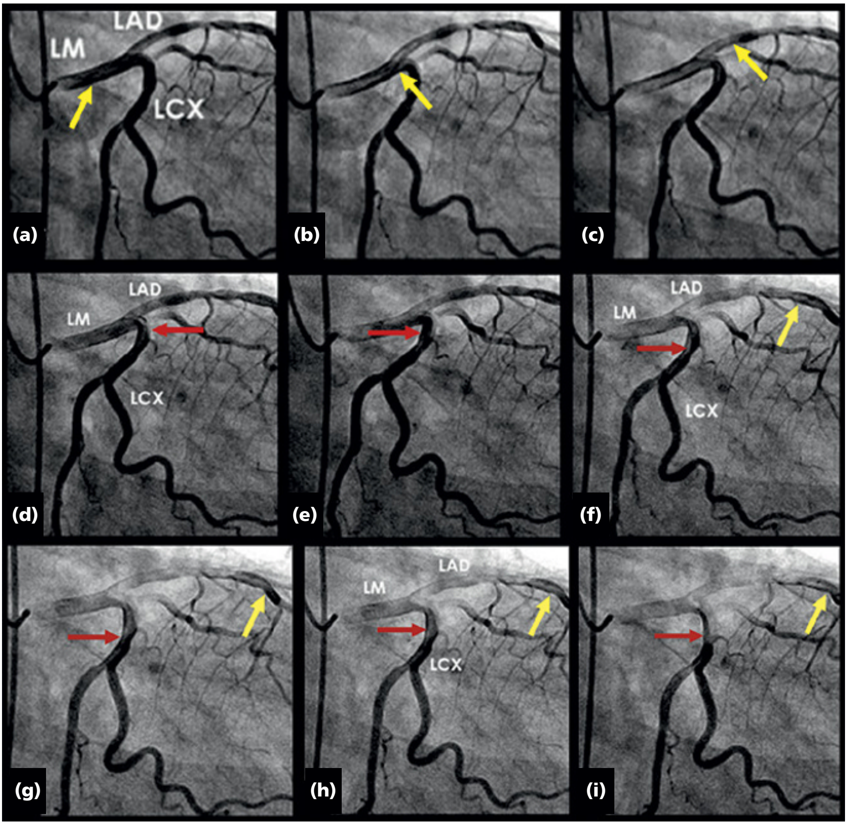

Figure 3.11 a–i. Coronary Flow at a Curve This is a series of nine consecutive images of a left coronary angiogram. The left main artery (LM), the left anterior descending artery (LAD) and the left circumflex artery (LCX) are filled with black contrast. The blood in white moves in, displaces the contrast. All images are filmed at 15 images per second or the interval between consecutive images = 0.067 second or 67 milliseconds. (a) The flow begins to enter the LM, as a white arrowhead at the ostium of the LM (arrow). This is the beginning (first image) of diastole. (b) The blood (in white) is seen at the proximal LAD, (arrow) while it is only at the ostium of the LCX. This is the second image of diastole. (c) The blood is seen further down the mid LAD (arrow) while it is still at the ostium of the LCX. This is the 3rd image of diastole. (d) In a higher magnification, the flow is at the ostium of the LCX, preferentially turns at the curve, along the carina (arrowhead). This is the 4th and last image of diastole. (e) The blood is at the proximal and mid LAD, while at the LCX, the blood just barely enters the LCX on the carina side. There is a thick layer of contrast at the outer curve of the LCX, opposite to the carina (arrowhead). This is the beginning of the recirculating flow at the peripheral layer. This is the first image of systole. (f) Now the blood in white color is seen twisted and move the outer curve of the proximal segment of the LCX. (g) The flow on the carina border is still homogenously white, even the speed is slow, because this is during systole. At the same time, there is turbulent movement of the blood (mixing of black and white) inside the peripheral layer (arrowhead). (h) Now the blood is still at the mid LAD (white arrow), while at the LCX, there is more turbulence at the peripheral layer (arrowhead). The reason for slow speed at the LAD is because the flow is in systole (3rd image of systole). (i) At this stage, the antegrade flow in the proximal LCX is larger, more prominent, and occupies more than half of the proximal LCX. The peripheral layer at the proximal LCX is now limited to a thin layer. The black color of the peripheral layer is more homogenous. It may be due to reversed flow during systole (arrowhead).

Table 3.3 List of locations to be focused in the right coronary artery

1. The ostium, its orientation, and the angle formed by the proximal segment of the artery with the aortic wall (to investigate the mechanism of ostial lesion) (**lesion 4R**)
2. The angle connecting the proximal to midsegment (to check the hinge motion)
3. The mid segment (to check the collision between antegrade and retrograde flow: most likely due to the water hammer shock phenomenon) (**lesions 1R** and **5R**)
4. The junction between the mid and distal segments (**lesion 2R** and to check the hinge motion)
5. The bifurcation with the posterior descending artery and posterior lateral branch (to check the recirculating flow caused by blood from convergent branches in a retrograde direction) (l**esion 3R**)

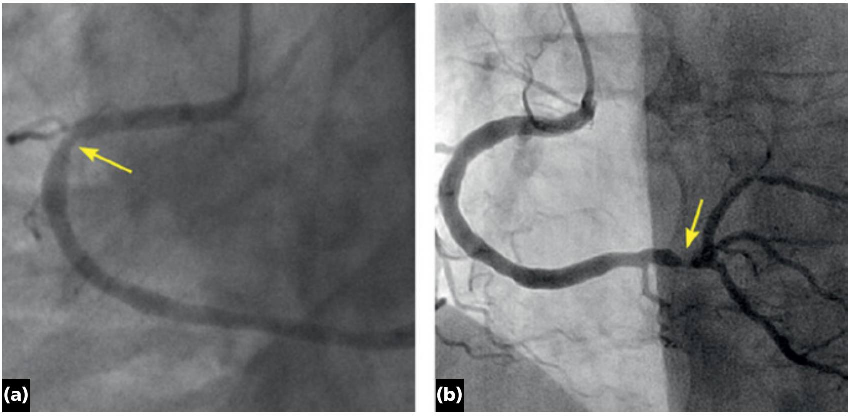

Figure 3.12 Vulnerable plaque at the Anterior Posterior (AP) caudal views. (a) The right coronary artery (RCA) is filled with contrast. There is a lesion at the junction between the proximal and mid-segment, mainly at the inner curve of the RCA. The cover of the plaque is seen as being opened at the proximal end, at the junction between the plaque and the normal intima. The lesion is most likely due to repetitive movement at a hinge. The location of the injury (proximal border of the plaque) is most likely due to recurrent hits from the antegrade flow, correctly targeted from an appropriate angle of attack. (b) This is a lesion in the distal segment of the RCA. Why was the lesion formed proximal to the bifurcation with the posterior descending artery? Why not distal to it? Could it be due to recirculating flow due to flow from two converging branches in a retrograde direction?

Figure 3.13b demonstrates a reverse rat-tail configuration, with severity increasing from distal to proximal direction. The rat-tail configuration suggests an antegrade progression of the pathological process originating from the proximal end from the RCA, whereas the reverse rat-tail configuration indicates a retrograde pathological progression originating from the distal end of the RCA.

In the Figure 3.14a–b, the lesion in Figure 3.14a exhibits a short, broad, and sharply pointed tip, in contrast, the lesion in Figure 3.14b features a long, narrow and pointed tip. Both patterns arise from the interaction between antegrade diastolic flow and the retrograde systolic pressure wave. In both cases, retrograde systolic pressure wave propagation is the dominant factor.

In the stenotic region of Figure 3.14a, the coronary lesion narrows abruptly from a short, wide segment to a severe constriction. In this configuration, the primary mechanism involves a rapid acceleration of flow, inducing a steeper pressure drop exacerbated by sharp top-to-nadir pressure gradients (with a narrow gradient profile). This pattern suggests both elevated systolic pressure and diastolic pressure.

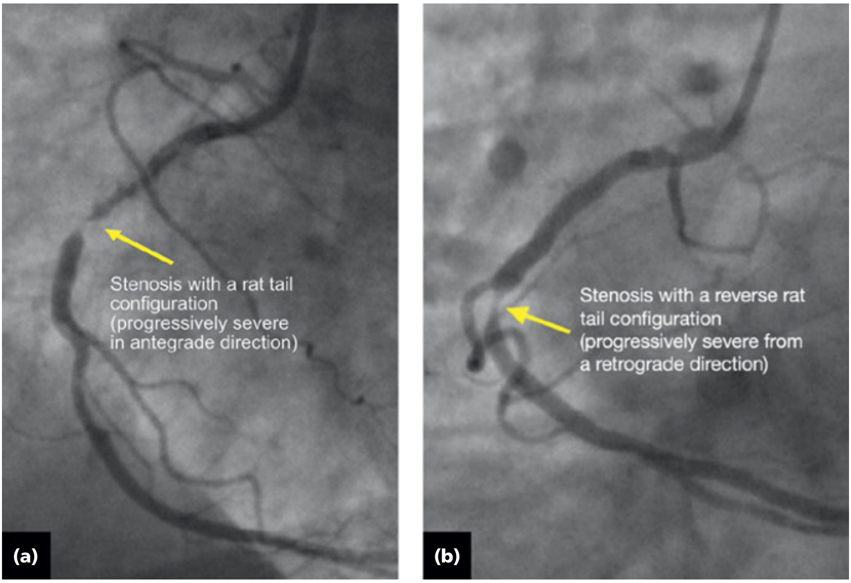
Stenosis with a rat tail configuration (progressively severe in antegrade direction)
(a)
Stenosis with a reverse rat tail configuration (progressively severe from a retrograde direction)
(b)

Figure 3.13 a–b. **Two lesions in mid right coronary artery (RCA) with different morphologies.** In figure a, the lesion has a rat-tail configuration. In figure b, the lesion has a reverse rat-tail configuration. Which mechanism(s) was (were) responsible for forming these different lesion configurations on the same location?

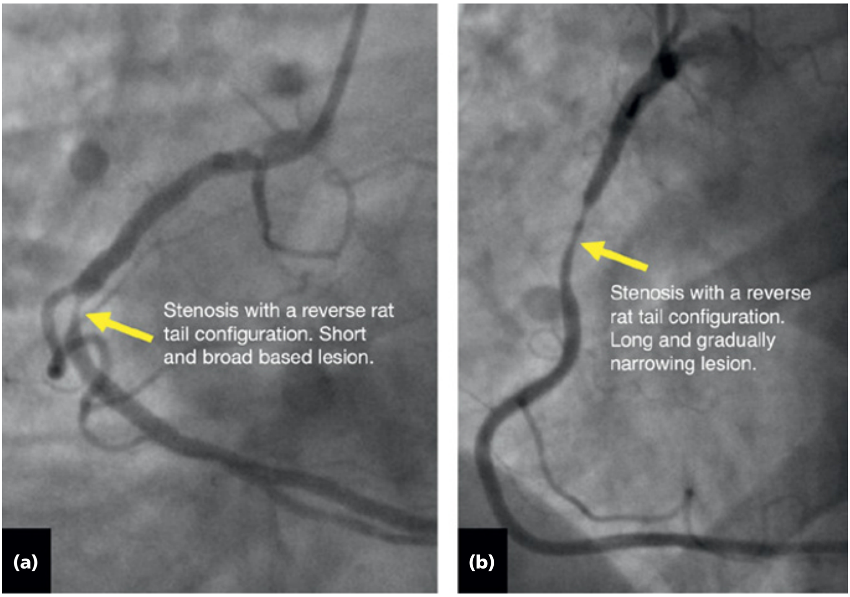
Stenosis with a reverse rat tail configuration. Short and broad based lesion.
(a)
Stenosis with a reverse rat tail configuration. Long and gradually narrowing lesion.
(b)

Figure 3.14 a–b. **Lesions at the center of the RCA.** In figure a-b, there is a critical narrowing at center of the mid segment of the RCA (arrow) of both arteries. Is there any difference in the shape and length of the lesion in these two arteries? Both have reverse rat tail configuration (gradually severe from distal to proximal direction). Which mechanism(s) was (were) responsible for the width and length of the reversed rat tail configuration?

The resulting localized instability drives frequent and intense pressure fluctuations, manifesting as vibration and fostering a high-energy state conducive to rapid morphological transformation. Consequently, the narrowing advances swiftly, with erosion and sediment transport reinforcing each other in an accelerating feedback loop [8].

In contrast, in the lesion of Figure 3.14b, the artery gradually narrows over a long stretch before reaching the same severe constriction, follows a more progressive and distributed mechanism. Instead of abrupt deposition of atherogenic material and localized turbulence, the artery undergoes continuous inner wall erosion or steady deposition along the narrowing path. As the channel constricts gradually, flow velocity increases more progressively, allowing for smoother adaptation and reduced turbulence. The pressure drop occurs over an extended distance, dissipating energy more evenly and leading to a more moderate top-to-nadir gradient. This results in lower-frequency pressure fluctuations and a more stable transition in flow conditions [7].

Lesions Carved by Recirculating Flow

Two lesions located in the distal RCA, one had a severe lesion at the distal segment of the RCA, prior to the origin of a posterior descending artery (PDA) (Figure 3.15a–b) while the other had lesion at the ostium of the PDA (Figure 3.16a–b). Do these lesions exhibit distinct characteristics? How to explain the mechanisms underlying their initiation and progression? Can personalized medicine be considered in these patients?

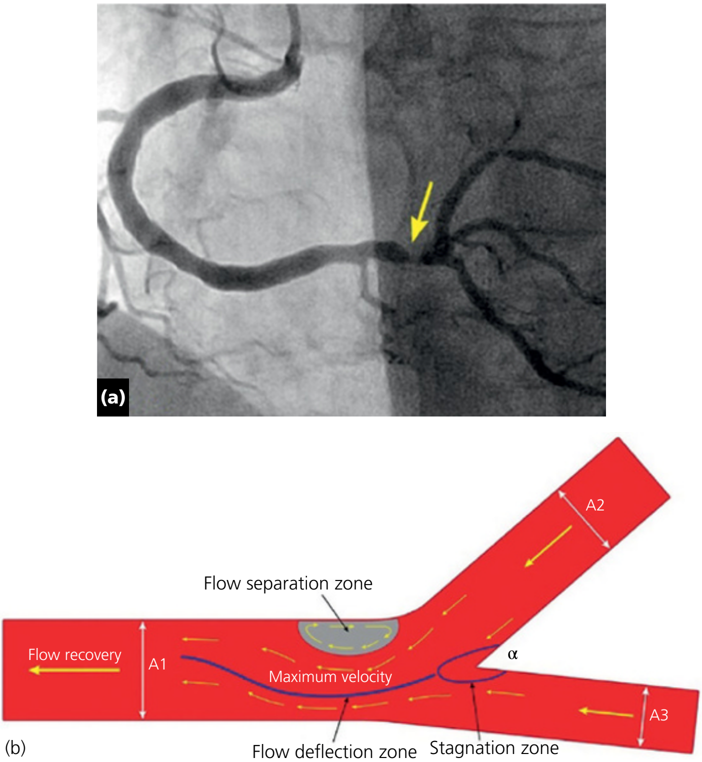

Figure 3.15 a–b. **Recirculating Flow.** (a) In a coronary angiogram of an elderly patient with a severe lesion proximal to the bifurcation of the distal right coronary artery and the posterior descending artery (PDA). (b) The blood converges from a large main branch and one smaller side branch. Because of differences in velocity, the flow at the inner curve recirculates and starts a slow atherosclerotic process.

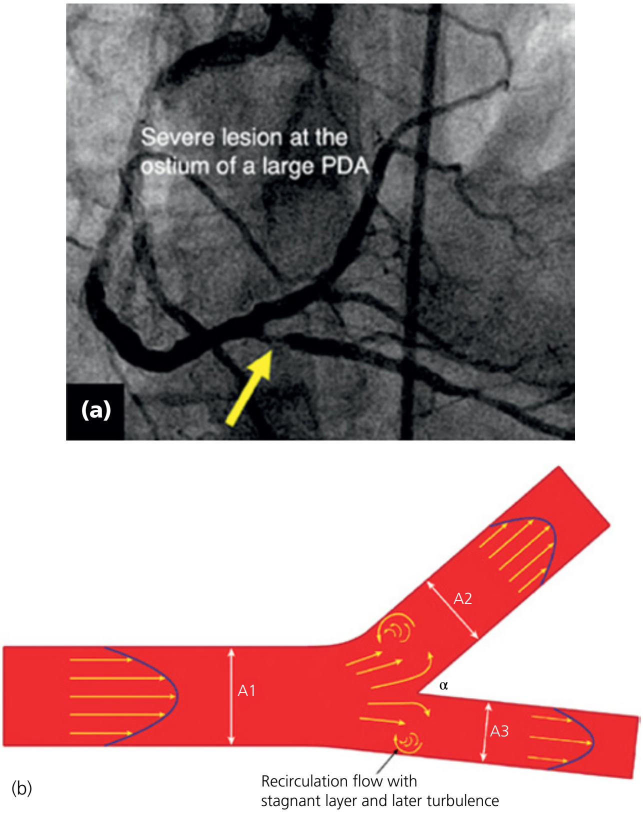
Severe lesion at the ostium of a large PDA
(a)
A2
A1
α
A3
(b)
Recirculation flow with stagnant layer and later turbulence

Figure 3.16 a–b. In this angiogram, there was significant narrowing at the ostium of the posterior descending artery (PDA). (b) When the blood arrives to a bifurcation, the blood enters the PDA on the carina side. When the differences in velocity between the central and peripheral layers reach a critical level, the flow at the peripheral layers recirculates and begins the formation of a lesion at the ostium of the PDA

In the Figure 3.15a–b, the lesion developed at the lower border of the distal RCA, proximal to the bifurcation of the distal RCA and the posterior descending artery (PDA). In this case, the blood converges from a large main branch and one smaller side branch in a retrograde direction. Because of differences in velocity, the flow at the inner curve recirculates and starts a slow atherosclerotic process at the distal RCA.

In the Figure 3.16a–b, in this angiogram, there was significant narrowing at the ostium of the PDA. When the blood arrives at a bifurcation, the blood enters the PDA on the carina side. When the differences in velocity between the central and peripheral layers reach a critical level, the flow at the peripheral layers recirculates and begins the formation of a lesion at the ostium of the PDA.

Analysis of the Dynamic Coronary Flow

New protocol for coronary images analysis When analyzing coronary angiographic images, it is crucial to select a projection that provides an unobstructed longitudinal view of the entire artery, free from superimposition by other arteries, branches, the liver, or shadows from spinal vertebrae. After the artery is fully opacified in black by the contrast agent, and as the contrast injection ceases while recording continues, the incoming blood appears in white moving in as it displaces the contrast. This sequence enables the observation of flow dynamics as the blood progressively replaces the contrast agent (Figure 3.17a–d) [6]. By the end of the sequence, when most of the contrast is replaced by blood, isolated pockets of contrast stagnation remain. These stagnant pockets represent the zones and mechanisms of high concentration of contrast (compression) or moderate concentration of contrast (rarefaction) as results of passage by water hammer generated pressure wave. The goal of the review is to identify and label the flows and lesions as below.

1. **Laminar flow:** In this pattern, the blood (in white) is seen flowing in parallel layers, without disruption nor mixing with contrast (in black) between layers. (Figure 3.17a–d and 3.9a–b)
2. **Disorganized flow:** In this pattern, the blood (in white) is mixed with the contrast (in black) in a disorganized pattern.
3. **Boundary layer:** when there is thick layer of contrast at the border of the artery while the blood in white moves at the center
4. **Retrograde flow** is when the flow moves from the distal or midsegment toward the proximal coronary segment. It is abnormal in any circumstance
5. **Delayed Antegrade flow** is when the flow moves from the proximal coronary segment toward the distal segment. It becomes abnormal if the speed is too slow.
6. **Pockets of retaining contrast:** when the contrast is almost replaced by blood and there are pockets of remnant contrast in the four locations highlighted in Figure 3.2a
7. **Codified coronary lesions:** the lesions in locations #1, #2, #3, #4 and #5 as identified in Table 3.1 and Figure 3.3.

GAME PLAY

In patients with cardiovascular (CV) disease, there are many clinical situations in which the pathophysiology is still not well elucidated. They are listed in Table 3.4

Laminar Flow

In a patient with normal coronary artery, the flow is mainly laminar. The laminar flow is defined as a smooth, orderly movement of fluid, with each layer flowing in parallel to one another and the streamlines in parallel to the axis of the artery. There is no mixing or diffusion between layers, and the flow remains stable and predictable. Due to friction with the wall, the speed of the flow is highest at the center and lower near the peripheries. Laminar flow is identifiable by its typical pointed tip, as shown in Figure 3.4a–d and 3.9a–b.

According to the Hagan-Poiseuille's law, blood flow in the coronary or aortic arteries is influenced by gradients, and the speed of the flow is highest at the origin and lowest near the end [11]. As a result, the proximal segment of the coronary artery is more prone to erosion injuries because the flow here is fast with high pressure, while the lesions secondary to accumulation from deposition is more common in the distal segment with the blood of lower pressure and at slower speed.

The laminar flow is very important because its presence guarantees the integrity of the intimal layers, prevent the deterioration to plaque rupture and acute coronary syndrome and prevent acute thrombosis and late in-stent restenosis after percutaneous coronary intervention (PCI) (Figure 3.5a–d and 3.16a–d; Video 3.1)

Video 3.1 Laminar flow.

Real-time Actions 1

No acute coronary syndrome with laminar flow A patient arrived with a moderate to severe lesion in the mid segment of the right coronary artery. There was smooth movement of laminar flow. There was no reversed flow at the lesion site. The blood pressure and LDL level was rigorously well controlled. The patient has been stable for the last four years [12] (Figure 3.17a–d).

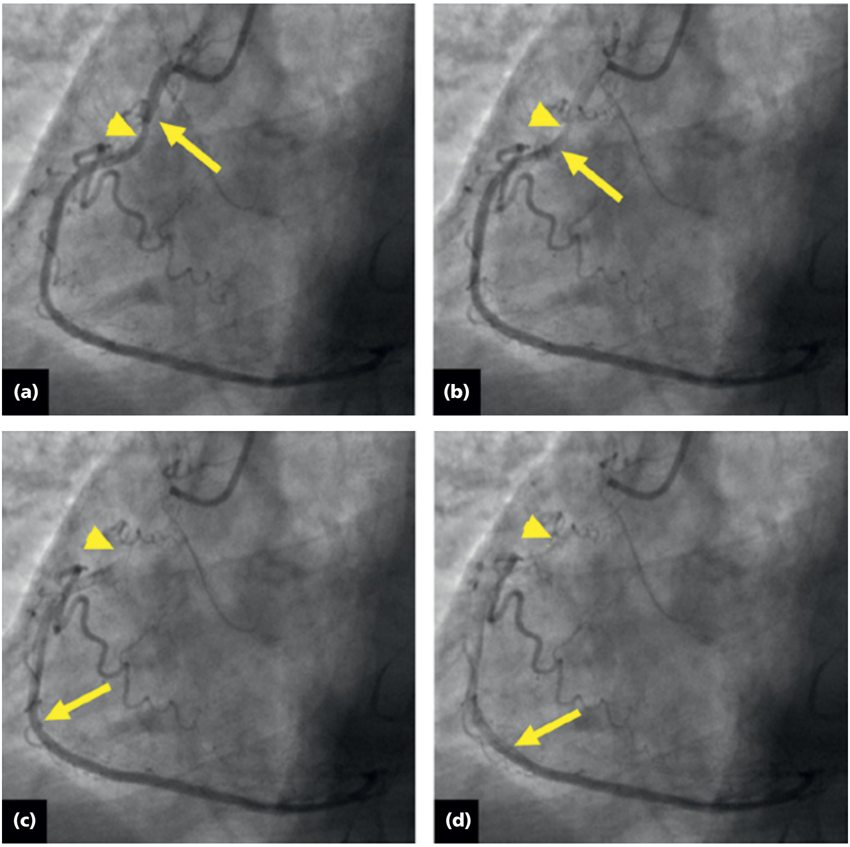

Figure 3.17 **a–b**. **Blood flow across a coronary lesion**. These images are of continuous sequence. A middle-aged man came with unstable angina and underwent coronary angiogram. (a) The artery was full of contrast in black. There was a 50% lesion at the mid segment of the right coronary artery (RCA). (arrowhead). (b) At the ostium of the RCA, the blood in white moved in at the beginning of diastole (arrow). (c) The blood in white color was now at the beginning of the RCA mid segment. (d) The flow of white blood passed the lesion section quickly without disorganized flow (turbulent flow) (arrow). The location of the lesion was marked with an arrowhead. The blood flow across a coronary lesion (d). The blood in white color was now at the end the RCA mid segment. There was no reversed flow at the lesion site. The flow of white blood entered the distal segment without disorganized flow (turbulent flow) at the lesion site (arrowhead).

Real-time Actions 2

Laminar flow after PCI guaranteed no ISR Before PCI, the baseline flow showed reversal flow and retention peripheral flow seen frequently at the mid RCA. After PCI, these abnormal flows disappeared. After long term follow-up (>1 year), patients with perfect flow did not develop in-stent restenosis. This new discovery could replace the measurement of FFR because if the speed of the coronary flow increases after PCI, the pressure should be lower (by the Bernoulli's equation) and the FFR ratio should be normalized without the need of a FFR wire. (Figure 3.18a–h; Video 3.2).

Video 3.2 Laminar flow after PCI prevents ISR.

Table 3.4 **Cardiovascular conditions analyzed by dynamic coronary flow.**

1. Progression or regression of coronary lesion of moderate stenosis
2. What is the mechanism of benefit from stenting? Could it be due to restoring laminar flow?
3. Chest pain and sudden death in patients with aortic stenosis (AS) and patent coronary arteries
4. Chest pain and sudden death in patients with anomalous origin of coronary artery from the opposite aortic sinus of Valsalva (ACAOS) and patent coronary arteries
5. Chest pain and sudden death in patients with dilated cardiomyopathy and patent coronary arteries
6. In patients with new dilated cardiomyopathy and low ejection fraction (EF), could a normal coronary dynamic flow predict the return to normal EF with treatment?

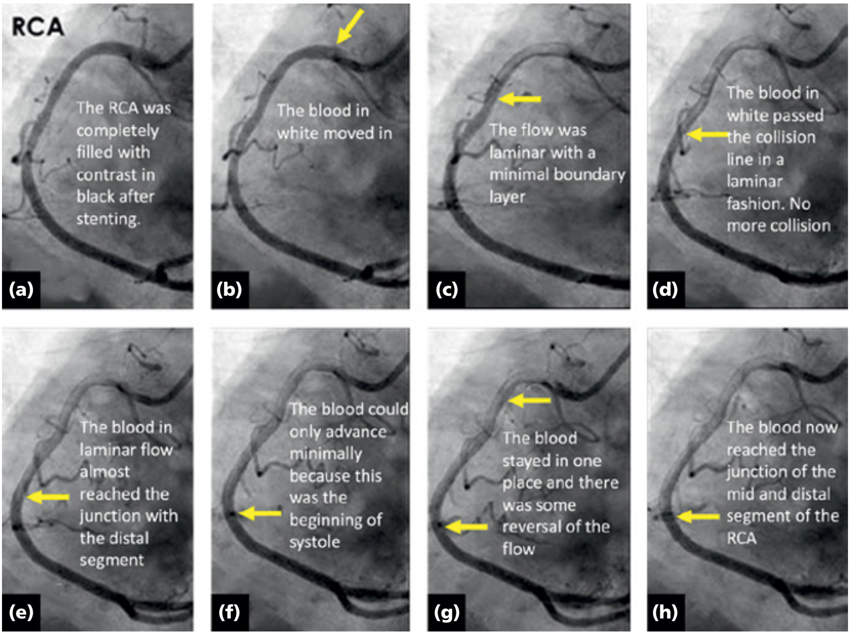
RCA
The RCA was completely filled with contrast in black after stenting.
(a)
The blood in white moved in
(b)
The flow was laminar with a minimal boundary layer
(c)
The blood in white passed the collision line in a laminar fashion. No more collision
(d)
The blood in laminar flow almost reached the junction with the distal segment
(e)
The blood could only advance minimally because this was the beginning of systole
(f)
The blood stayed in one place and there was some reversal of the flow
(g)
The blood now reached the junction of the mid and distal segment of the RCA
(h)

Figure 3.18 a–h. This is a series of eight consecutive images of an angiogram of the right coronary artery (RCA) right after stenting at the mid segment. (a) The artery was filled with contrasts. (b) The blood (white) was seen entering the ostium of the RCA (arrow). This is the beginning of diastole. (c–h) The blood (white) moved forwards without encountering the retrograde pressure wave. Most likely the arterial wall was scaffolded by the stent and it interrupted the propagation of retrograde pressure wave on the arterial wall. The flow was laminar and there was no significant retrograde flow. The blood pressure and level of LDL have been well controlled. The patient has been well with regular activities in the last four years.

Real-time Actions 3

Reversed flow in coronary anomalies In patients with the anomalous RCA originated from the left sinus, they can have chest pain with patent coronary arteries. By analysis of the coronary flow, the results showed 90% of patients with chest pain had persistent reversed flow with ejection of contrast from the RCA to the right coronary sinus (Figure 3.19a–f and Video 3.3). In these patients, there were significant slow or no flow in the distal coronary

Video 3.3 Reversed flow in coronary anomalies.

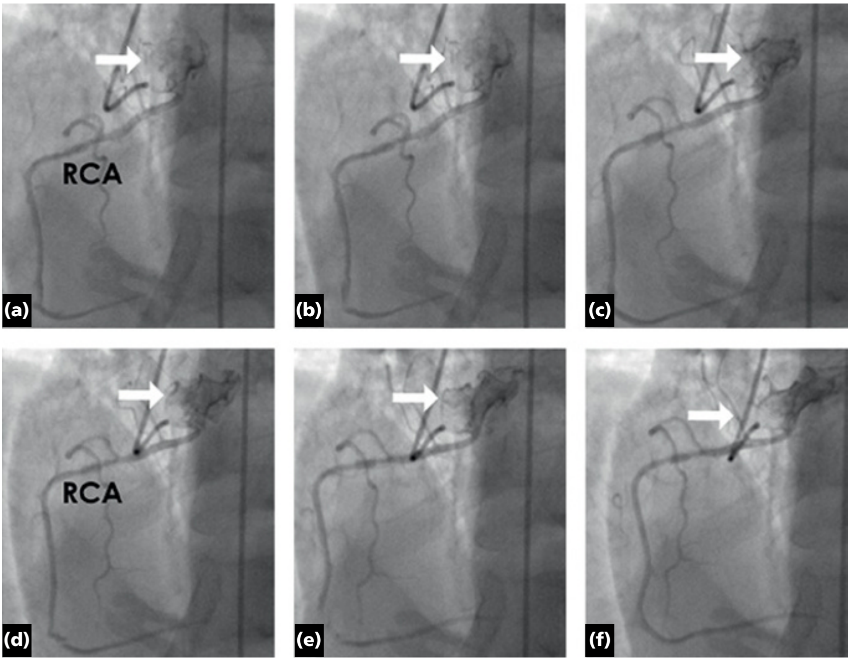

Figure 3.19 Reversed Flow in the Right Coronary Artery. This is a series of six sequential images separated by 0.06 second each (15 images per second). (a) The right coronary artery (RCA) originated from the left sinus. The contrast filled completely the RCA. The diagnostic catheter flipped out. Contrast (black) could be seen coming out of the RCA ostium, spilling in the aortic sinus (arrow). (b) and (c) The area of spillage became darker and darker because more contrast was spilling out (arrow). (d) Contrast (black) could be seen coming out of the RCA ostium and spilling into the aortic sinus in a disorganized fashion (i.e., turbulent) (arrow). (e) The cloud of contrast expanded (arrow). (f) The area of contrast became larger and darker because more contrast was spilled (arrow).

segment lasting more than eight seconds (120 frames) even though the arteries were patent. The three above observations (slow flow at distal segment, reversed flow in the proximal coronary arteries and persistent retrograde ejection of contrast into the coronary sinus) are the mechanisms of ischemia and sudden death in patients with the anomalous RCA originated from the left sinus. [13]

Real-time Actions 4

Reversed flow in aortic stenosis In patients with significant aortic stenosis (AS) and patent coronary arteries, analysis of coronary flow showed significant slow or no flow in the distal coronary segment lasting more than eight seconds (120 frames). There was also significant recurrent reversed flow in the proximal coronary segment (>90%). The 2 above observations (slow flow in distal and reversed flow in the proximal coronary arteries) are the mechanisms of ischemia causing chest pain, syncope and sudden cardiac death in the AS patients with patent coronary arteries [14–15].

Real-time Actions 5

Delayed arterial flow in dilated cardiomyopathy In patients with dilated cardiomyopathy and diffuse mild chest discomfort, the analysis of the coronary flow showed significant slow or no flow in the distal coronary segment lasting more than eight seconds (120 frames) even the arteries were patent (Video 3.4). The speculation is that no flow in distal segment and reversed flow in the proximal coronary arteries are the cause of ischemia and sudden death in patients with dilated cardiomyopathy [16]. In contrary, for patients with dilated cardiomyopathy and normal arterial phase, these patients had their ejection fraction recovered to normal level after treatment with sacubitril-valsartan [17].

Video 3.4 Prolonged arterial phase.

ANALYSIS OF CORONARY FLOW BY ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

CHALLENGES

Coronary angiography traditionally provides a static visualization of the coronary lumen, limiting its capacity to reveal the dynamic nature of blood flow disturbances that may precede lesion formation.

Artificial intelligence (AI) application in angiography aims to overcome this limitation by analyzing frame-by-frame changes in contrast propagation and vessel motion. This approach is grounded in fluid mechanics and acoustic theory, particularly the principles of pressure wave interaction and the water hammer phenomenon, which help explain how lesions tend to form at specific vascular locations due to localized flow disruption and pressure buildup. Relevant AI pipelines can be designed to identify and classify four lesion-prone locations – 1,2, 3 and 4- based on temporal contrast patterns and anatomical positioning (Figures 3.20 and 3.21).

As shown in Figure 3.20, an AI application can extract necessary information from each frame of angiogram videos in an angiogram imaging process. After that, the application can generate suitable segmentation and masks for possible regions of interest (ROIs) based on trained machine learning models. The segmented or detected objects can be put into another data processing phase to return the final outputs [17].

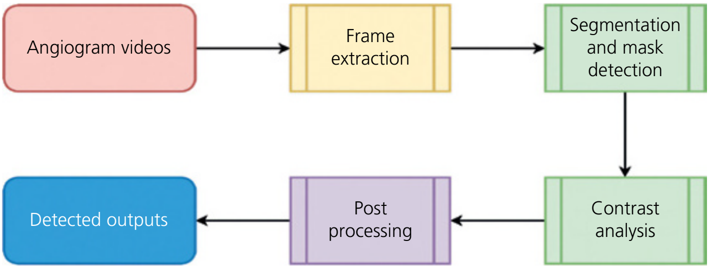

Figure 3.20 The Artificial Intelligence workflow for the angiogram imaging process.

ACOUSTICS ANALYSIS

Theoretical Basis

Applying acoustic principles to coronary flow dynamics offers a robust framework for interpreting contrast behavior and predicting lesion development. In fluid-filled structures such as coronary arteries, pressure waves travel and interact in ways that mirror acoustic phenomena seen in tubular systems. The "water hammer" effect - originally described in industrial hydraulics – occurs when a rapid pressure surge reflects off a distal obstruction or an abrupt change in flow. In the coronary context, the water hammer event happens during

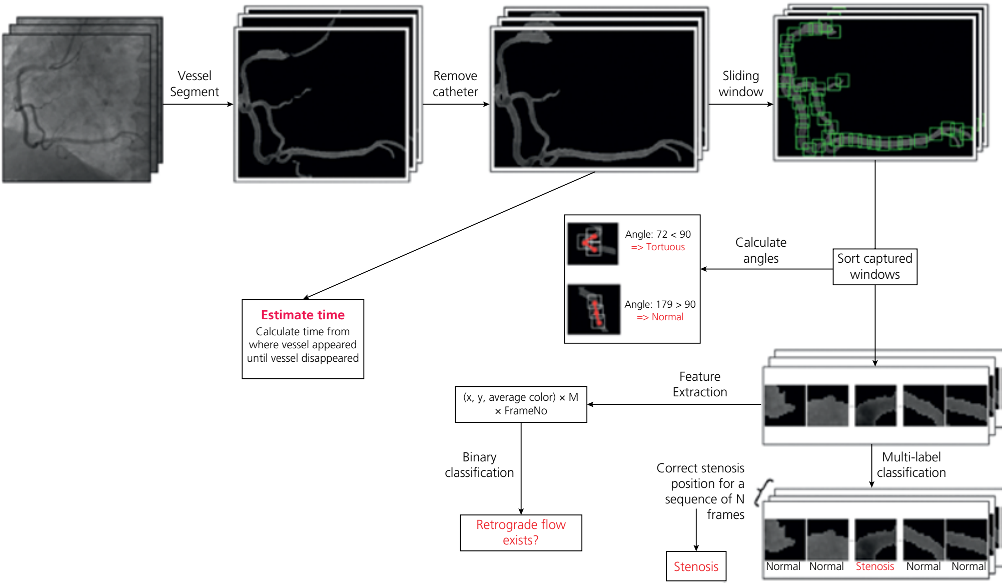
Vessel Segment
Remove catheter
Sliding window
Sort captured windows
Calculate angles
Angle: 72 < 90
=> Tortuous
Angle: 179 > 90
=> Normal
Estimate time
Calculate time from where vessel appeared until vessel disappeared
Feature Extraction
(x, y, average color) × M × FrameNo
Binary classification
Retrograde flow exists?
Multi-label classification
Correct stenosis position for a sequence of N frames
Stenosis
Normal
Normal
Stenosis
Normal
Normal

Figure 3.21 The Artificial Intelligence workflow for the angiogram imaging process.

GAME PLAN

Dataset Preparation

The dataset comprises coronary angiogram sequences collected from multiple patients at 15 frames per second. Each video is decomposed into individual grayscale frames, and corresponding segmentation masks are generated either manually or using a dedicated segmentation model. These masks delineate the coronary artery lumen on a per-frame basis to account for motion caused by the cardiac cycle. Where available, expert annotations are included to indicate lesion location and severity. Based on timing or contrast dynamics, frames are labeled according to the cardiac phase - diastole, systole, or transitional states. This structured dataset forms the foundation for model training and quantitative analysis of contrast behavior over time.

Data Preprocessing

Preprocessing begins by identifying the frame at which contrast opacification is maximal, typically represented by the lowest mean grayscale intensity across the vessel mask. This frame marks the start of the dynamic flow analysis. From this point forward, all subsequent frames are used to assess contrast washout. The pixel values within each frame are normalized, and segmentation masks are applied frame-by-frame to account for vessel movement. For each segmented vessel region, the mean grayscale intensity is computed, particularly in the final frames of the angiogram, to quantify remnant contrast concentration. Regions that retain a high contrast signal are likely to correspond to areas of impaired flow or pressure turbulence. Sliding window averaging may be used to smooth short-term fluctuations across consecutive frames.

Model Architectures

The AI pipeline integrates two main model types. The first is a segmentation network based on a modified Residual Recurrent U-Net (R2U-Net) with attention mechanisms. This architecture is well-suited for capturing fine, dynamically moving vascular structures and provides accurate delineation of coronary vessels across time. The second model is a temporal classification network, implemented as a lightweight Transformer. It receives sequences of segmented frames and learns to predict the likelihood of each region belonging to one of the four lesion-prone sites (1, 2, 3, 4) based on the timing of the frame, anatomical context, and contrast retention.

Training and Evaluation

Both segmentation and classification models are trained in a supervised fashion. The segmentation network is optimized using binary cross-entropy and Dice loss to handle class imbalance and ensure spatial accuracy. The classification network is trained using cross-entropy loss and evaluated using precision, recall, and F1-score to assess its ability to identify lesion locations and severity correctly. For remnant contrast estimation, mean absolute error is used as a regression metric. Evaluation is performed through patient-level cross-validation to prevent data leakage and ensure model generalizability. Together, these methods enable a physiologically grounded, data-driven approach to identifying flow disturbances and predicting lesion formation in dynamic coronary angiography (Figures 3.22 and 3.23).

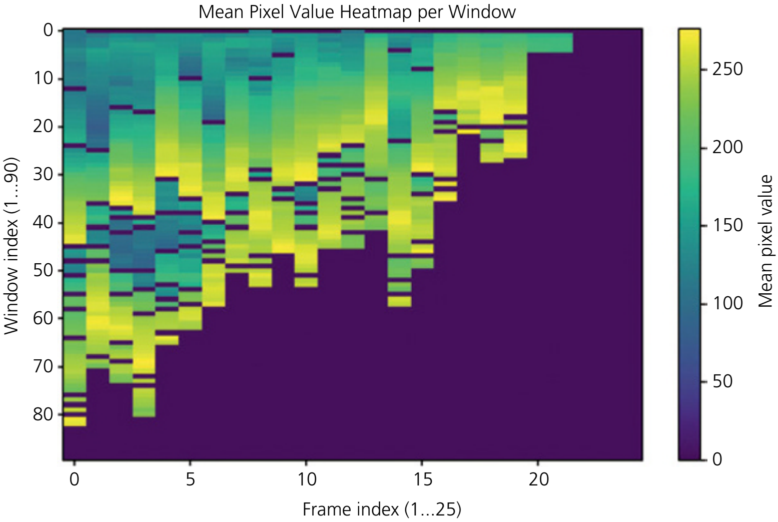

Figure 3.22 The Artificial Intelligence analysis of the heatmap.

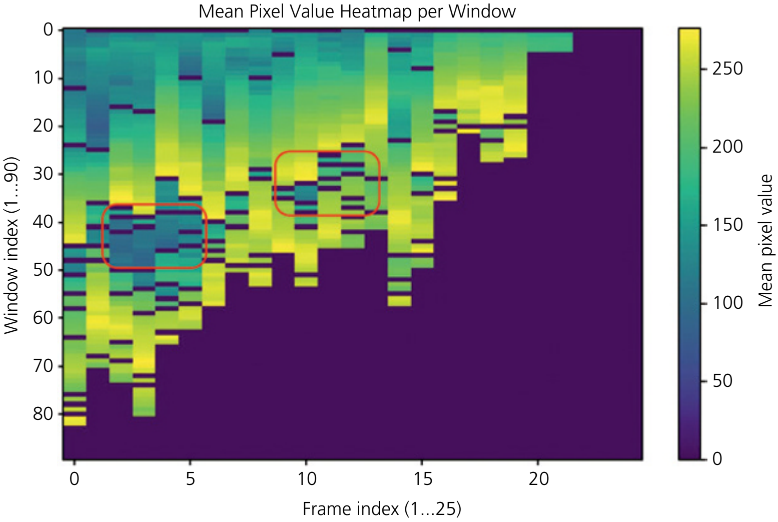

Figure 3.23 The Artificial Intelligence analysis of the compression and rarefaction zones.

systole, particularly when high-pressure systolic waves suddenly overtake low-pressure diastole flow. These interactions result in alternating zones of compression and rarefaction along the artery, which may correlate with sites of intimal injury and atherosclerotic lesion formation. This theoretical framework establishes a foundation for integrating AI methods to detect and classify these dynamic flow disturbances using angiographic imaging.

Contrast Flow Behavior as Acoustic Signals

When visualized through dynamic coronary angiography, the contrast medium behaves in a manner analogous to acoustic wave propagation. Areas of high contrast density represent compression zones - akin to antinodes in standing wave patterns - while regions with moderate contrast represent rarefaction. The transition between these zones often marks significant changes in flow pressure and direction. In practice, this can be observed as contrast lingering or dissipating differently across segments of the artery over time. By treating contrast propagation as an acoustic signal, AI models can be trained to recognize patterns in contrast retention and washout that correlate with wave interference, reflection, and damping effects. These temporal and spatial fluctuations in contrast behavior are not random; they follow fluid dynamic laws and can be quantified using metrics derived from pixel intensity and motion over sequential frames. In this way, contrast flow becomes a surrogate for acoustic signal mapping, enabling the detection of functional abnormalities even in the absence of structural stenosis.

Mapping Lesion Zones to Acoustic Model

The integration of AI with the acoustic model enables the systematic identification of lesion-prone regions based on measurable flow patterns. The four primary lesion zones - designated 1, 2, 3, and 4 - can be mapped to specific acoustic phenomena. Zone 1 typically corresponds to the most severe lesions and is identified as a high-pressure compression zone occurring at the transition from diastole to systole, where retrograde pressure waves create maximum turbulence. Zone 3 represents a secondary compression zone with moderate lesion risk. At the same time, Zone 2 correlates with a rarefaction region arising during the systole-to-diastole transition, often linked to milder lesions. Zone 4, typically near the ostium, reflects the mildest flow disturbance and is associated with late or minimal contrast retention – an acoustic low-pressure zone. AI models trained on temporal angiogram data, with segmentation and intensity analysis, can classify each zone by analyzing these acoustic-equivalent features. This mapping allows the AI system to detect where a lesion is most likely to develop and characterize the mechanism of injury based on wave dynamics, providing both spatial and physiological insight into coronary artery disease progression.

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CHAPTER 4

Guides

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

An optimal guide provides a stable platform for the operator to advance devices to the coronary ostium, through tortuous arterial segments and across tight lesions. The guide is selected according to the size of the ascending aorta, the location of the ostia to be cannulated, and the degree of tortuosity and calcification of the coronary segment proximal to the target area.

BEST PLAYERS

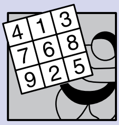
aka Standard of Excellence

Once engaged in the ostial segment, the tip of the guide needs to be positioned with atraumatic coaxial alignment. As an interventional device is pushed forward and across the coronary lesion, any guide with its tip held still, not being displaced, will be the ideal guide for the procedure.

In a simple case with easy access, the Judkins guide, even in a relaxed position (just barely outside the coronary artery ostium) in the aortic sinus, can provide an adequate platform to advance the device. It is the ideal guide position for aorto-ostial lesion stenting. In complex cases, where more resistance is encountered, any selected guide with its secondary curve well positioned and standing firm against the opposite aortic wall would provide the strong and stable platform needed for device advancement. This chapter discusses the use of a guide through the femoral approach. The use of a guide via the transradial approach is discussed in Chapter 8.

GAME PLAY

Practical Analysis of Guide Design



The most used guides are the Judkins, Amplatz, and extra backup (EBU) guides. Others that have a niche in various situations include the multipurpose (MP) guide for right coronary artery (RCA) bypass or a high left main (LM) takeoff and the left internal mammary artery (IMA) guide for the superiorly oriented graft and the right and left coronary bypass graft (Figure 4.1).

The guides are classified as passive or active support. Passive support is the strong support given by the inherent design of a guide with good backup against the opposite aortic wall or aortocoronary sinus and stiffness from the material from which it is manufactured. Additional manipulation is generally not required. Active support is typically achieved either by manipulation of the guide into a configuration conforming to the aortic root or by subselective intubation with deep engagement of the guide into the coronary vessels [1].

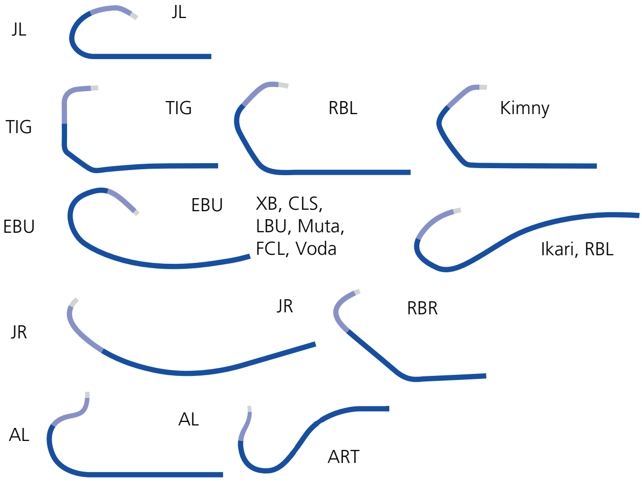

JL
JL
TIG
TIG
RBL
Kimny
EBU
EBU
XB, CLS,
LBU, Muta,
FCL, Voda
Ikari, RBL
JR
JR
RBR
AL
AL
ART

Figure 4.1 Different shapes of guides: JL = Judkins left, JR = Judkins right, AL = Amplatz left, TIG = Tiger, EBU = extra backup, RB = right back-up curve, RBL = right back-up left curve, RBR = right back-up right curve, XB = extra back-up, CLS = CLS™curve, LBU = left back-up curve, Muta = MUTA™left curve, FCL = femoral curve left, ART = ALLRIGHT™left curve.

The Judkins Guide

The Judkins left (JL) guide is designed for coronary angiography (CAG): its primary (90°), secondary (180°), and tertiary (35°) curves fit the aortic root anatomy, so it can engage the LM ostium without much manipulation (Figure 4.2). It knows where to go unless it is thwarted by the operator (in the transfemoral approach). However, in the transradial approach, much more manipulation is required to engage the coronary ostium. Because of the 90° bend at its tip, the JL does not make perfect coaxial alignment. On many occasions, even when the secondary curve does not sit well on the opposite aortic wall or coronary sinus, diagnostic angiography can still be performed satisfactorily, although there is no adequate support for the advancement of interventional devices during percutaneous coronary interventions (PCI) [1].

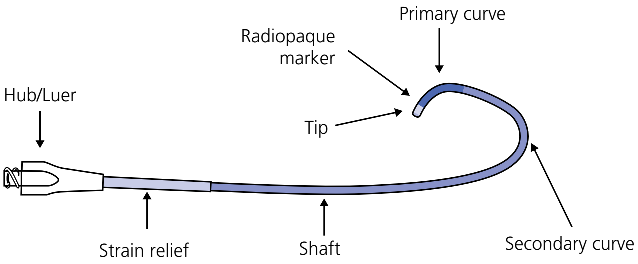

Primary curve
Radiopaque
marker
Hub/Luer
Tip
Strain relief
Shaft
Secondary curve

Figure 4.2 The main structures that define the physical characteristics of a guide: curves, tip, hub, shaft, etc.

Tips and Tricks

****Manipulations to enter the left main ostium** After the JL guide has been placed in the left sinus, in an anterior–posterior (AP) view, by slight push and pull movement with minimal **counterclockwise torque**, the left coronary artery (LCA) is engaged. If the guide does not select the LM ostium, then a small injection into the coronary sinus may locate the LM ostium. If the LM is above the tip of the guide, pull the guide back and repeat the counterclockwise torque. If the LM is anterior to the tip of the guide, make a small counterclockwise torque to twist the tip anteriorly. If the LM is seen posterior to the tip, make a small clockwise torque to point the tip of the guide posteriorly. This is a general maneuver that can be used with any guide when the catheter or guide does not enter the artery directly.

The Amplatz Guide

The left Amplatz (AL) guide is designed with its secondary curve resting against the noncoronary posterior aortic cusp, whereas in the right Amplatz guide, the secondary curve rests against the left aortic cusp. This guide offers a firm platform for the advancement of the device. It is best in the case of a long LM, with a downgoing left circumflex artery (LCX) or in superior takeoff. However, because the tip of an AL is pointed slightly downward, there is a higher danger of ostial injury causing dissection. There are, therefore, short-tip Amplatz guides, which provide the same level of support but decrease the risk of coronary ostial trauma (Figure 4.3).

The Multipurpose Guide

This guide is straight, with a single minor bend at the tip. Except for a few cases of high LM takeoff or downward RCA, which can be cannulated well with this MP guide, it is not routinely used for native coronary PCI.

The Extra Backup Guide

The names of these EBU guides vary (Voda or XB, EBU, C, Q, or geometric curve guides) according to the manufacturer. Their common design is that the long tip forms a fairly straight line with the LM axis or the proximal ostial RCA, so they can provide a better transition angle with less local friction. They also have a long secondary curve, which is designed to abut the opposite aortic wall, so the tip in the coronary artery is not easily displaced and hence provides a very stable platform [2].

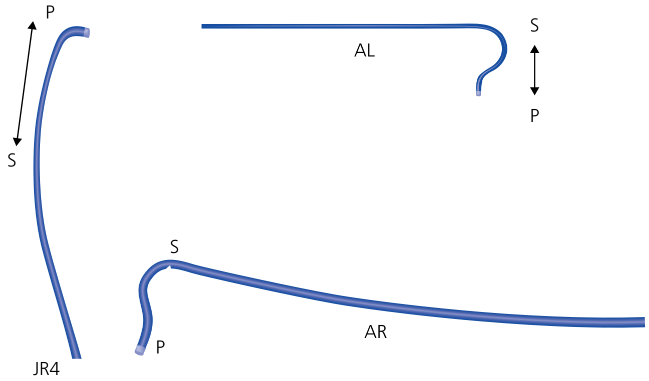


Figure 4.3 The curves in the Judkins right and Amplatz catheters (JR = Judkins right, AR = Amplatz right, AL = Amplatz left, P = primary curve, S = secondary curve).

GUIDE MANIPULATIONS

Safety Measures

In any situation, the basic safety measures should be applied rigorously when manipulating guides. They are listed in Box 4.1.

Tips and Tricks

***Advancement through tortuous iliac artery** Because of excessive tortuosity of the iliac artery, rotations at the proximal end do not transmit similar motion to the distal tip. If not constantly watched, the guide can twist on itself. Simple, gentle movement of the guide in and out, often over a very short distance, transmits torque to the tip [3]. In these situations, a 23-cm femoral sheath may help to overcome the problem of iliac tortuosity. A simple technique is to torque a guide still cannulated inside by a stiff 0.38-inch wire inserted through a Y adapter. Manipulate the tip near the ostium, remove the stiff wire, flush the guide, and then engage the tip in the ostium [3]. If the iliac artery is tortuous and contains mild to moderate plaques, advance a balloon catheter into the guide and position the balloon so that it extends halfway beyond the tip of the guide. Inflate the balloon at low pressure. This technique prevents the guide from scraping against the atherosclerotic plaque and reduces the risk of iliac artery dissection.

***Dampening of arterial pressure** The guide can cause a fall in diastolic pressure (ventricularization) or in both systolic and diastolic pressure (dampened pressure) (Figure 4.4). The causes can be a significant lesion in the ostium, coronary spasm, non-coaxial alignment of the guide, or mismatch between the diameter of the guide and the arterial lumen (Figure 4.5). When dampening of the aortic pressure is caused by a small Judkins FL4 guide, due to its short secondary curve, the tip of the guide would point up into the wall of the LM. This guide should be exchanged for a larger one or one with side holes, allowing passive blood flow into the distal coronary artery. The drawbacks include suboptimal opacification of the artery because contrast escapes through side holes and, very rarely, decreased backup support due to a weakened guide shaft and kinking of the guide at the side holes if the guide is excessively manipulated. However, the most common cause of ventricularization is an ostial lesion. If the blood pressure is dampened – not due to an ostial lesion while a balloon, stent, or wire is already in the coronary artery – then advancing any of these devices further will back out the guide and restore the normal blood pressure tracing.

BOX 4.1 STANDARD SAFETY TECHNIQUES

1. Aspirate the guide vigorously after it is inserted *into the ascending aorta* for any thrombus or atheromatous debris floating into the guide
2. Insist on generous back-bleeding and introduce devices into the Y adapter on flush to avoid air embolism
3. Flush frequently to avoid stagnation of blood and thrombus formation inside the guide
4. Constantly watch the tip when withdrawing an interventional device from the coronary artery and especially in patients with ostial or proximal plaques
5. Watch the blood pressure curve for dampening to avoid inadvertent deep engagement of the tip
6. During injection, keep the tip of the syringe pointed down so any air bubbles will float up and not be injected into the coronary system

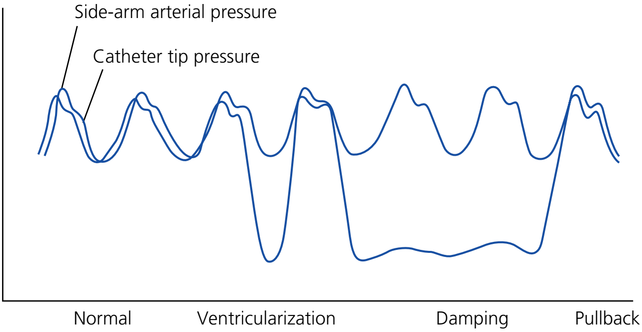


Figure 4.4 Ventricularization of the aortic pressure.

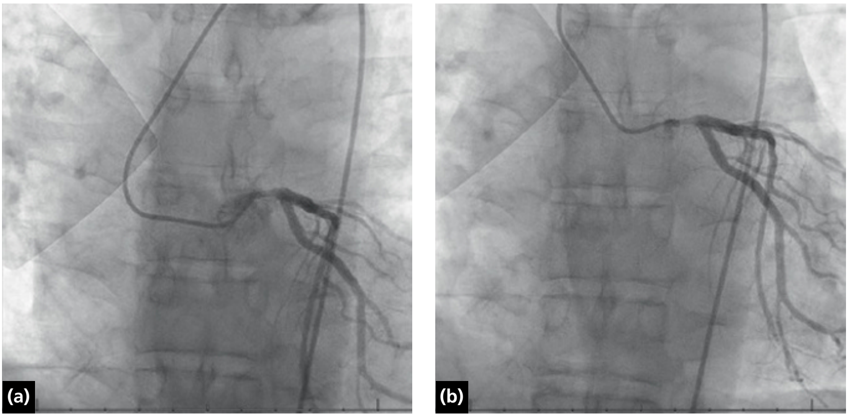


Figure 4.5 (a) The secondary curve of this Judkins JL4 catheter is short; hence, the tip is pointing up into the wall of the left main and does not cause left ventricularization. (b) The secondary curve of this Judkins JL5 catheter is longer; hence, the tip is co-axial with the left main stem and obstructs the flow causing left ventricularization.

ADVANCED AND EXOTIC TECHNIQUE

How to Make a Side Hole in a Regular Guide

The diagnostic 0.035-inch wire is inserted into the guide and a 12–14G regular needle is used to puncture a hole 3–5 cm from the tip. The needle is rotated to form a good hole, and the material removed from the wall of the guide is carefully discarded [4]. However, with a side hole, the distal end of the guide may become weak and kink, and catheter extension might not advance smoothly in such guides.

Tips and Tricks

***Checking stability and potential of backup capability** Under fluoroscopic guidance, forward advancement of the guide should demonstrate a tendency to further intubate the coronary artery rather than prolapse into the aortic root. If the tip slips out, it means that the guide does not provide sufficient backup. It may need to be changed for another with better support. Active intubation of the guide may be attempted if the guide tip is soft, the target artery is sufficiently large, and there are no ostial or proximal lesions. This temporary deep-seating position provides the support needed to advance the device across the lesion. Once the device is in place, the guide should be withdrawn to the ostium or completely disengaged.

****Simple coaxial position or active support position?** Coaxial guide alignment with the ostium is more important than an active support or "power position" because it allows the operator to gently advance and retract the guide as needed, ensuring proper stent position and contrast opacification. Because almost all interventional devices (stent, cutting balloon, directional, rotational ablative, thrombectomy or distal protection device, etc.) are rigid and have a large profile, non-coaxial alignment of the guide may lead to injury, endothelial denudation causing thrombus, or dissection of the ostium of the coronary vessel. Aggressive guide intubation prevents stent deployment at an aorto-ostial lesion [1].

****How important is the guide's external diameter in ostial obstruction?** The external diameter of a guide could cause significant obstruction to the coronary artery flow. This is especially true for 7- and 8-French (Fr) guides if the artery is small or there is a plaque at the ostium. It can cause periprocedural ischemia [4] (Figure 4.6).

*****If the guide is too long** In cases of interventions through long saphenous vein grafts (SVG) or IMA grafts, care must be taken to ensure that there is sufficient guide length to reach distal sites with extra-long (145 cm) balloon catheters or short guides (80 cm), or the guide can be shortened and capped with a flared, short sheath one size smaller.

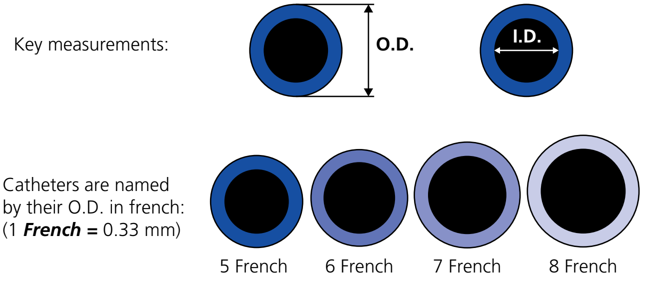

Key measurements:
O.D.
I.D.
Catheters are named by their O.D. in french: (1 ***French*** = 0.33 mm)
5 French
6 French
7 French
8 French

Figure 4.6 The key measurements of the size of a guide: outer diameter (O.D.) and inner diameter (I.D.).

ADVANCED AND EXOTIC TECHNIQUE

How to Shorten a Guide

First, cut the guide with a scalpel. While the guide is still engaging the artery with a wire across the lesion, clamp the guide with a hemostat to prevent blood loss during the shortening procedure. Care must be taken that the scalpel does not damage the wire. Next, a standard sheath that is 1-Fr size smaller than the guide is cut with 2 cm of sheath attached to the hub. The newly shortened sheath tip is then "flared" with a vessel dilator that is 1-Fr size larger than the sheath. This is done by inserting the tapered end of the dilator in a retrograde fashion into the sheath tip. Remove the dilator and reinsert it into the shortened sheath in an antegrade fashion, and thread the sheath on

(*Continued*)

the indwelling wire through the dilator. Finally, the flared end of the sheath stub is advanced over the cut end of the guide with a firm friction fit. The hemostatic clamp is removed, and the side port is attached to the manifold. The newly assembled system is carefully aspirated through the manifold to ensure that no air is trapped within it [5]. The problem with a shortened guide is that it has poor torque transmission during vessel engagement and guide manipulation.

Compatibility of the Guide Internal Diameter

During complex intervention, if the double balloon technique is needed, the minimal required lumen diameter is calculated by adding 0.006 inch to the combined diameter of the largest portions of the two balloon catheters. As the lumen size becomes larger due to innovations from manufacturers, the selection of any guide is up to the size of the lumen and its accommodating capacity (Table 4.1). In general, in modern large internal diameter 6-Fr guides (mainly Launcher, Medtronics, Dublin, Ireland), it is possible to accommodate usually two 3.5-mm balloons for kissing inflation or a combination of one 4.0-mm and one 3.0-mm balloon. In the classic crush technique, a 7-Fr guide is needed, whereas only a 6-Fr guide is needed for a step crush technique. Before carrying out a control angiogram, one of the balloons has to be removed in order to have good opacification of the artery. If two microcatheters are intended for use in chronic total occlusions (CTOs), a 7-Fr guide is necessary. If there is a need for a microcatheter and intravenous ultrasound (IVUS), it is obligatory to start with an 8-Fr guide. The internal diameters of different guides are listed in Table 4.2.

Table 4.1 Guides: Size and compatibility. Courtesy of Dr. Yves Louvard

Guide	Devices	PCI technique
5 Fr	Balloons, stents, IVUS Rotational atherectomy 1.25 mm	
6 Fr	GuideLiner, distal protection device Atherectomy “cutting” balloon Orbital atherectomy 1.25 mm Rotational atherectomy ≤1.5 mm	Kissing balloon
7 Fr	Jostent, ePTFE-covered stent Rotational atherectomy 1.75 mm Trapping balloons (CTO PCI)	Bifurcation: “kissing” stents
8 Fr	Rotational atherectomy 2.15 mm Trapping balloons (CTO PCI)	CTO PCI
9 Fr	Rotational atherectomy 2.25 mm	

Table 4.2 The internal diameters of guides

	Vista BT (inches)	Mach 1 (inches)	Launcher (inches)
5 Fr	0.056	NA	0.058
6 Fr	0.070	0.070	0.071
7 Fr	0.078	0.081	0.081
8 Fr	0.088	0.089	0.091

Tips and Tricks

****When should a guide with side holes be used?** When there is ventricularization or dampening of aortic pressure, corrective measures using a guide with side holes can give false security because the tip of the guide might be located under a plaque, and manipulation or injection of contrast could cause severe dissection. A guide with side holes should ideally be used in PCI for CTOs of the RCA where anterograde collaterals are present. This generally guarantees anterograde flow even during deep guide intubation, which permits distal opacification during contrast injections, thus avoiding possible ischemia.

*****Guides for unusually wide ascending aorta** In extremely enlarged aortas due to long-standing aortic insufficiency or hypertension, the usual guides to cannulate the ostium do not fit the large aorta. If the guide has a Judkins shape, the primary curve is prolonged to 7, 8, or 9 cm in length. For the Amplatz catheter, the AL-5 or AL-6 should be used. However, the radius of the curvature is increased so the tip remains lower. For a guide with an EBU curve, the length of the distal tip is prolonged to fit the extra-wide aortic sinus.

ADVANCED AND EXOTIC TECHNIQUE

Shaping the Guide

Stainless steel wires (0.035 inch) are formed into the desired shapes and kept under sterile conditions. 6-Fr MP guides are mounted on the preformed wires and heated using an industrial warm air blower. Then the guides are immersed in cold saline, and the wire is removed. However, shaping is best accomplished with polyethylene catheters, which are quite rare today [6].

Tips and Tricks

****How to stabilize a guide with an ostial stented lesion** Often it is difficult to selectively intubate the ostium of a coronary artery that has previously been stented and is now restenosing at the stent. The ostial stent may extend into the aortic sinus and have various degrees of in-stent restenosis. Not every guide could engage the ostium, so a first wire could be passed into the stent via a lower stent strut and then be used as a support to lift the guide and make it more coaxial with the stent ostium. A second working wire could be advanced through the central lumen into the distal vessel. The Amplatz-type guides are probably better suited to these cases because pushing the guide would lift up its tip. This permits placing the tip in the central lumen of a previously implanted stent (this is practically impossible to do with the Judkins guides). By using a wire with a large loop at the tip, the wire could finally enter the main lumen of the stent [7].

****Safety when using a large guide** When using a large-diameter guide, there is often a significant step-off/transition between the inner diameter of the guide and the outer diameter of the wire. This transition may act like a wood plane or cheese grater, damaging endothelium and collecting debris as the guide is advanced. A smaller diagnostic catheter within the guide or a small balloon catheter with the balloon positioned halfway across the tip of the guide and inflated at low pressure may smooth the transition from wire/diagnostic catheter/guide for advancement (4-Fr within a 6-Fr guide or a 5 Fr within a 7-Fr guide). Once inside the coronary ostium, the diagnostic or balloon catheter may be removed [8].

*****Double guides for complex PCI** If there is a need for two guides in complex PCI of vessels with a large ostium, two smaller guides can be used. The disadvantage is that there are two punctures for the two sets of guides. However, with two guides rather than one large guide cramped by many devices inside it, there is more room for contrast injection, so visualization of the coronary arteries during PCI is improved. With two guides, the movement of interventional (stent, balloon), diagnostic (IVUS), or distal protective (filter) devices can be easier. If the sheath can be changed to a larger one, two diagnostic catheters can be inserted into one 8-Fr sheath, or one guide and one diagnostic catheter can be inserted into a 9- or 10-Fr sheath without the need for a new puncture [8].

*****Identify two guides for complex PCI** If there is a need for two guides in complex PCI, use the right femoral for the right coronary and the left femoral for the left coronary. The same applies for the radial approach.

*****Manipulation of two guides for complex PCI** If there is a need for two guides in complex PCI of vessels with a large ostium, two smaller guides can be used. Engage the right coronary guide **first** because it needs to be torqued, whereas the left guide just needs to be advanced further. If there is a need for further manipulation of the left guide, advance a wire into the right coronary to stabilize the right guide.

****Guide support** Excellent guide support can significantly facilitate every step in PCI, including wiring and balloon or stent delivery, and can be accomplished by (1) using large-diameter (7- or 8-Fr) guides, (2) using more supportive shapes (such as Amplatz or EBU), (3) ensuring coaxial alignment of the guide with the coronary ostium, and (4) applying deep guide intubation. Deep guide intubation carries the risk of pressure dampening, compromising blood flow and leading to ischemia, and causing coronary dissections.

SELECTION OF GUIDES

Judkins Guide

A Judkins guide is selected according to the width of the aortic root, the location of the ostia to be cannulated, and the orientation of the coronary segment proximal to the target lesion. The segment between the primary and secondary curves of the JL guide should fit the width of the ascending aorta: 3.5 cm, 4 cm, 4.5 cm, 5 cm, 6 cm, etc. The ostia can be low, high, anteriorly, or posteriorly located. The ostial or proximal segment can be directed upward, downward, or horizontally. For the average American patient, a 4-cm JL guide is often adequate when working with a transfemoral approach. A half-size downsize is necessary for the transradial approach, i.e. JL 3.5 cm must be the first choice. For Asian patients, a 3.5-cm JL guide usually fits well. In patients with a very superior direction of the LAD or in those with a narrow aortic root, a smaller size guide with a tip that is more anteriorly pointed will provide a coaxial position of the tip. In patients with a horizontal or wide aortic root (e.g. chronic aortic insufficiency or uncontrolled high blood pressure), a JL guide with a long secondary curve (size 5 or 6) will fit the width of the ascending aorta well (Figure 4.7). Once in the left coronary sinus, gentle counterclockwise rotations of the guide will frequently direct the tip anteriorly and enter it into the LM (Videos 4.1–4.3).

Video 4.1 Patient was told of having small left anterior descending artery.

Video 4.2 The left anterior descending artery was seen quickly when pulling back the Judkins left catheter.

Video 4.3 Left anterior descending artery seen well with smaller Judkins Left while the catheter was torqued counter-clockwise to point the tip up.

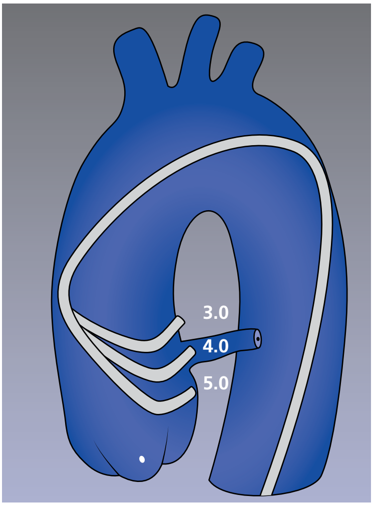


Figure 4.7 The importance of catheter size in coaxial position of catheter tip against coronary ostium. The smaller guide tends to curve in on itself, while larger guides will stay widely opened, prolapsing in the left sinus below the coronary ostium.

Tips and Tricks

****Non-coaxial position of a small judkins guide** If a small JL guide is chosen, with its tip not coaxial to the LM, the tip will point superiorly to the wall. In that position, even though there is no dampening of aortic pressure, an injection of contrast agent in young patients may not cause dissection, but in elderly patients with many unsuspected plaques, it can cause a small, localized dissection (Figure 4.5a, b).

***Guide that is too large** The JL tip points in a cranial direction, depending on the length between the primary and secondary curves and how far the heel or secondary curve is advanced into the aortic root. As a guide is advanced down the aortic sinuses, if its tip remains in the vertical axis of the ascending aorta and does not curve upward to reach the left ostium, this catheter is too large. It should be changed to a smaller one.

***Guide that is too small** If the JL guide is smaller than needed or the distance between the primary and secondary curves is too short, the guide would be advanced too far into the aortic root. It would double back on itself inside the sinuses of Valsalva.

***Engagement of a judkins right guide** The basic maneuver for cannulation of the RCA is to advance the guide into the aortic root, then rotate the shaft clockwise while gently withdrawing it so that its tip can select the RCA ostium. When the RCA arises more anteriorly or above the right cusp, the tip of the JR guide will not stay coaxial inside the right ostium. The coaxial position can best be appreciated by viewing the tip of the guide as a ring in a head-on position with the right anterior oblique (RAO) 30° view (Figure 4.8, and see Figure 2.6a).

Amplatz Guide

Selection of the proper size for an Amplatz guide is essential. Size 1 is for the smallest aortic root, size 2 for normal, and size 3 for large. Attempts to force engagement of a preformed Amplatz guide that does not conform to a particular aorta, aortic root, or aortic sinus only waste time and increase the risk of complications. If the tip does not reach the ostium and keeps lying below it, the guide is too small. If the tip lies above the ostium, or the loop cannot

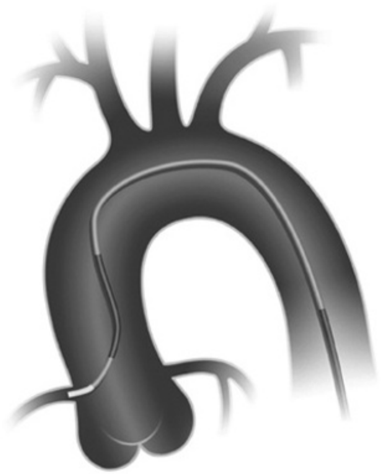


Figure 4.8 The tip of the Judkins right guide can easily cannulate the right coronary artery ostium; however, as the shaft of the Judkins right does not rest on the opposite aortic wall, the backup force of the Judkins right is low. Source: Quoc Nguyen.

be opened, the guide is too large. When the right coronary ostium is very high, the AL guide may be used to engage it. For arteries that lie in the mid-portion of the right sinus or lower, a right Amplatz with a much smaller hook should be used. The guide is advanced into the ascending aorta behind the long, soft distal segment of the wire, with the tip pointed toward the patient's left until the guide lies on the posterior or non-coronary sinus. The best projection is RAO 30°, which clearly defines anterior and posterior directions. Moreover, this projection permits clear verification of the coaxial position of the guide. After being flushed well, the guide is advanced slowly with the tip pointing upward and anteriorly. The guide should be torqued counterclockwise when the initial position of the tip is anterior to point to the tip more anteriorly while being pushed more superiorly. The tip is rotated and retracted until it engages the LM ostium. If the guide points toward the non-coronary sinus, it must be slightly pushed and turned clockwise to engage the LM and counterclockwise to engage the RCA (Figure 4.9).

Tips and Tricks

****Optimal position of an amplatz guide** Once the tip of the Amplatz guide is inside the LM or RCA ostium, the primary and secondary curves of the guide should form a closed loop with the tip coaxial to the ostial segment. This is the correct guide position. If the guide is pulled back, its tip could dip further into the LM and increase the risk of LM dissection. Under fluoroscopy, while the guide is in a relaxed mode, the undesirable position is a more open loop with the tip pointing down the inferior wall of the ostial segment.

***Withdrawal of an amplatz guide** Amplatz catheters must be carefully disengaged from the coronary artery. Simple withdrawal from the vessel in a manner similar to a Judkins catheter can advance the tip farther into the vessel and cause dissection. To disengage the Amplatz catheter, first advance the guide slightly under fluoroscopy to prolapse the tip out of the ostium, then rotate the guide so that its tip is moved away from the ostium before pulling the guide – this is called the "push and turn" maneuver.

****Withdrawal of an amplatz guide after balloon inflation** After angioplasty or deployment of a stent, the balloon is deflated. If the balloon is pulled out, the tip of the Amplatz (or any) guide will tend to be sucked in deeper. This is a situation to avoid. The first best

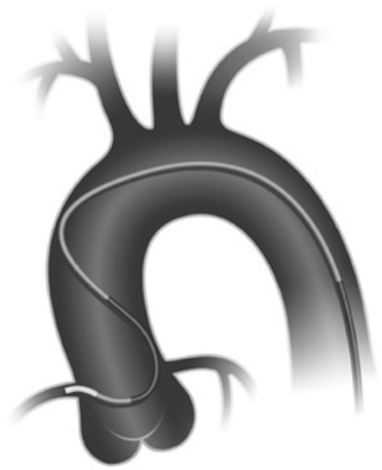


Figure 4.9 The Amplatz left guide for the right coronary artery. With the extra support from the contralateral wall, the Amplatz left provides a sturdy platform for stent/device delivery. Source: Quoc Nguyen.

technique is to pull the balloon out while simultaneously pushing the guide in to prolapse the guide out. The procedure has to be done under fluoroscopy to monitor the calculated movement of the guide tip. If the above maneuver fails, the second technique can be used. The deflated balloon should be advanced slowly to back out the guide. As the guide stops backing out, it is withdrawn slowly while watching the tip in order to avoid scratching the inferior aspect of the ostial segment. Once the tip is sensed to point unsafely down the ostial segment, the balloon is advanced again to lift the tip and back out of the guide further. This maneuver is repeated until the tip of the guide is totally out of the ostium. Then the guide and the interventional device can be retracted as needed. The tip is less likely to cause damage if it is retracted over the shaft of a device catheter.

Multipurpose Guide

Most operators start by placing the tip of the MP guide at the posterior sinus or non-coronary cusp in the 30° RAO position. The guide is advanced with the tip pointed toward the spine until the guide begins to buckle (or **above** the level of the target ostium). When a loop is formed, slight clockwise rotation flips the tip to the left cusp. Withdrawal of the guide at the moment of that flip is usually required to maintain the correct position. If the tip does not enter the LCA directly, advancing the tip by gentle counterclockwise rotation will cannulate the LM ostium.

The RCA is approached in the 45° left anterior oblique (LAO) position. From the left cusp, the tip is directed anteriorly and to the patient's right (**above** the level of the RCA ostium). Then the guide is rotated clockwise and slightly withdrawn to engage the right ostium. The MP guide is also very useful in situations where the aorta is dilated and it is not possible to obtain a stable position with other types of catheters. A simple push and pull can regulate the length of the catheter curve.

How to make a curve at the distal tip The key is to make the secondary curve long enough to cover the aortic sinus, then position the tip higher than the target ostium so that when the guide is pulled back, its tip will descend and enter the ostium.

Extra Backup Guide

Most operators advocate advancement of the tip of the guide with a wire protruding into the ascending aorta, at the aortic valve sinus, below the coronary ostium. The wire is then removed.

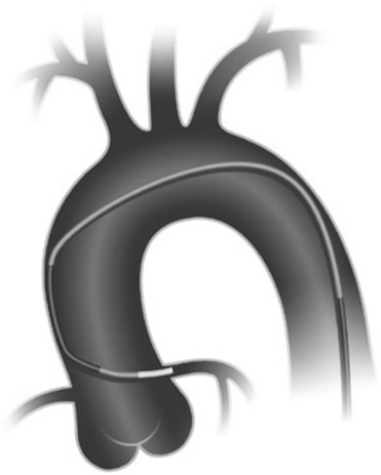


Figure 4.10 The extra backup (EBU) guide for the left system. A long segment of the shaft of the EBU guide rests steadily on the contralateral aortic wall so that the EBU guide provides the strongest support for device advancement. The tip of the EBU guide has the best coaxial orientation. This EBU guide is indicated when deep intubation is needed, such as in long left main, and when the left circumflex artery forms a 90° angle with the left main. Source: Quoc Nguyen.

The guide is then flushed, advanced, or withdrawn gently while torquing clockwise to point it upward; then it can be torqued clockwise to move the tip posteriorly or counterclockwise to move the tip anteriorly, like an Amplatz guide, until it enters the LM or RCA (Figure 4.10). The EBU guide is very useful for the RCA when extra support is needed and in cases of shepherd's crook.

DIAGNOSTIC CATHETER FOR LM LESIONS

A significant lesion in the LM can be suspected when there is (1) typical angina at a low level of activity or exercise testing, (2) typical angina at rest, (3) typical angina after a large meal, (4) significant diffuse ST–T segment depression at a low level of exercise testing, and (5) no increase or decrease in blood pressure on exercise stress testing.

Tips and Tricks

***Catheter position in suspected LM lesion** When an LM lesion is suspected, a short-tip JL catheter should be chosen in the AP position. The catheter is positioned below the LM ostium, beneath the cusp, where an injection of 10 mL of contrast may opacify the cusp and give a general assessment of the LM segment. Then the tip of the catheter is manipulated to slowly engage the LM ostium, avoiding an uncontrolled jump into the artery due to its pre-shaped configuration. If there is no dampening or ventricularization of the aortic pressure, then a small amount, 2–3 mL, of contrast is injected in the AP, or shallow RAO, or shallow LAO with caudal tilt (spider view) view to detect the severity of the lesion.

****How many views do you need after detecting an LM lesion?** Once an LM lesion is confirmed, only two more views are needed: the AP cranial and the AP caudal. These two views give all the information on the LAD and LCX needed for bypass surgery. If LM PCI is contemplated, the LAD and LCX need to be visualized in more views, especially the ostial segment of both branches.

****Dampening pressure** Dampening of the aortic pressure can be caused by an LM lesion and, more frequently, by a mismatch between a large-sized catheter and a small coronary ostium. Gradual repositioning and withdrawal of the catheter may eliminate pressure dampening. An injection of contrast agent in case of dampening of pressure, even a small amount, can further lift the plaque and cause a dissection that can become disastrous.

GUIDE FOR LAD LESIONS

To reach an LAD lesion, the guide has to engage the LM ostium. The LM is in a superior and anterior position, so any guide with a tip pointing superiorly, such as the JL guide, should provide stable and coaxial alignment. In patients with a very superior direction of the LM or those with narrow aortic root, a smaller size guide will point the tip more anteriorly or the EBU guide can help to provide stronger backup. In the case of high coronary takeoff, an MP or Amplatz guide would easily cannulate the LM ostium. In patients with a horizontal or wide aortic root, a Judkins guide with a long secondary curve (size 5 or 6), or an AL-type guide may be needed.

GUIDE FOR LCX LESIONS

Cannulation of the LM for PCI in the LCX can usually be achieved with the JL guide if the LM is short. In case of high coronary takeoff, use an MP or Amplatz guide. In patients with a horizontal or wide aortic root, a Judkins guide with a long secondary curve (size 5 or 6) or an AL-type guide may be needed. Because the tip of the Judkins guide points superiorly, better axial support for LCX lesions can be obtained using an Amplatz or EBU guide. If the LM is long, an EBU guide is needed in order to position the tip of the guide as close as possible to the ostium of the LCX. In this position, the advancement of interventional devices (e.g. the stent) is easier because the devices do not have to turn around a sharp curve at the junction between the LM and the LCX.

Tips and Tricks

***Pointing toward the LCX** In case of a short LM or separate ostium of the LCX, if the tip of the first Judkins guide does not point toward the LCX, slightly withdraw the guide and turn clockwise. The tip will point posteriorly toward the LCX. If this maneuver does not achieve satisfactory results, change to a larger size or an Amplatz-type guide with the tip pointing down. If the LM is very short, a JL is good. A size 1.5 Amplatz will allow acceptable cannulation without over-engagement. However, watch for dissection caused by an over-engaging tip (Box 4.2).

****Selection of guides for PCI** If the LM is short and there is no acute angle at the bifurcation with the LCX, a JL guide may be the first best choice. If the LM is long and the angle between the LM and LCX is acute, an EBU guide should be chosen. The rationale for this choice is that the tip of an EBU guide can be positioned deep inside the LM and very close to

BOX 4.2 DIRECTION OF TORQUING DURING DEEP-SEATING MANEUVER

1. Toward the LAD, counterclockwise rotation
2. Toward the LCX, clockwise rotation
3. In the RCA, clockwise rotation

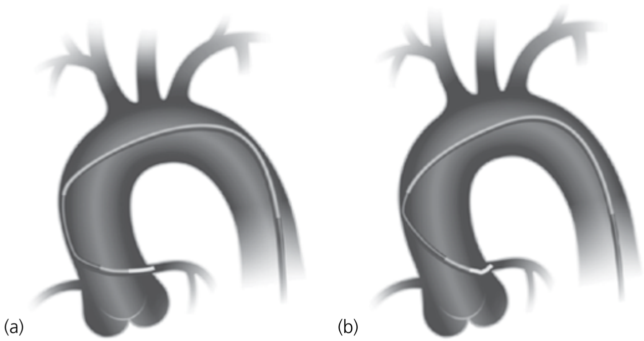


Figure 4.11 Comparison between (a) the extra backup (EBU) and (b) the Judkins curves. A long segment of the shaft of the EBU guide rests against the contralateral aortic wall, whereas only a short segment of the Judkins left does so. This explains the higher backup force of the EBU guide. Source: Quoc Nguyen.

the ostium of the LCX, so the acuity of the LM and LCX angle is nullified, making smoother the transition between the LM and LCX (Figure 4.11).

*****Rotational amplatz maneuver** To enhance the support role of a JL guide (active support or "power position"), if the length of the guide is appropriate, with the tip hooked in the LM, the JL guide is gently pushed down until the whole curve sits well in the left sinus. At that time, the guide is torqued gently and clockwise so the tip still points to the LM, and the whole guide simulates the position achieved by an Amplatz guide. The guide should be torqued over the shaft of an interventional device (stent, balloon, IVUS, etc.). This is called the rotational Amplatz maneuver. The operator should not feel any resistance when attempting this maneuver. After the interventional device has been advanced and positioned in place, the guide is withdrawn from the artery by reversing the earlier torquing energy, i.e. gentle clockwise rotation so the guide can untwist itself while being slowly pulled back.

This technique should be performed with a soft-tip guide in a coronary artery large enough to accommodate the guide. There should not be disease at the ostium or proximal or distal segment of the LM. It is important that the size of the Judkins guide in most cases is half a size larger than the size necessary to engage the artery. For example, if a JL 3.5 guide is good for engagement, it is in most cases not good enough for the Amplatz maneuver; a JL 4.0 guide is much better. However, an alternative is to exchange the JL guide for an Amplatz or EBU guide that can provide stronger (passive) support, less friction at the LM–LCX bifurcation, and safer advancement of interventional hardware without excessive manipulation resulting in unintended or unexpected prolapse of the tip of the guide outside the LM [9].

GUIDE FOR RCA LESIONS

The RCA usually arises anterolaterally from the right coronary cusp. In most cases, its proximal segment has a horizontal configuration and forms a 90° angle with the lateral border of the aorta. In the case of an acutely angled takeoff, the "shepherd's crook," the angle is smaller than 90°. When the RCA is directed caudally, the downward angle is more than 90°. However, there are other minor variations, including the slightly anterior or posterior placed ostium, or the one with anomalous origins, that can make cannulation or alignment of the guide difficult.

Tips and Tricks

****Selection of guides for horizontal takeoff angle** In the majority of cases of RCA with horizontal takeoff, a JR 4 guide can easily engage the ostium. When a JR guide fails to cannulate the right ostium, a right Amplatz is the next option. If this fails, an AL with backup from the opposite wall of the aorta will usually achieve cannulation of the ostium and provide the required backup.

****Selection of guides for superiorly oriented takeoff angle** When the shepherd's crook or a markedly superior orientation of the RCA is encountered, a guide with the tip pointing up is necessary. The JR guide, which is effective in diagnostic angiography, may not provide sufficient backup; therefore, the Amplatz left guide is usually selected. Other guides with a superiorly directed tip, such as the hockey stick, the left saphenous venous bypass, the IMA, or the EBU, can cannulate the vessel, although they offer poor backup support. These preshaped guides may eliminate the need for extensive torquing and are particularly useful in elderly patients or in patients with very tortuous iliac arteries, which sometimes make guide manipulation very difficult.

****Selection of guides for inferiorly oriented takeoff angle** In this caudal orientation of the proximal segment of the RCA, aggressive engagement of the tip of a regular JR guide can abut the lateral wall and cause dissection. Guides with inferiorly directed tips, such as the right saphenous venous bypass, MP, and Amplatz guides, may achieve more effective coaxial alignment with the proximal vessel segment.

****Avoiding selective entry of the conus branch** If the guide keeps entering the conus artery, do one of two things: (1) change the guide for a larger one, or (2) approach the RCA from a posterior direction – position the guide above the sinus and rotate the guide counterclockwise to enter the main RCA first.

****Deep-seating an RCA guide** In a non-coaxial situation, backup support will not be adequate for the advancement of interventional devices. Thus, the guide would be better aligned by additional clockwise rotation to allow the tip to engage deeper into the ostium. This maneuver is performed in the LAO view. When the interventional device is advanced into the coronary artery by the right hand, additional pressure should be put on the guide by the left hand placed firmly on the patient's thigh near the femoral sheath so the guide does not back out. While the device catheter is advanced, the assistant should pull the wire back slowly to decrease friction inside the device catheter, thus facilitating its advancement. If the guide needs to be deep-seated, it is advanced over an interventional device (stent, balloon catheter, etc.) while applying clockwise torque. Once the guide is deep-seated, the interventional device is advanced and positioned. After achieving the position needed, the guide is withdrawn with gentle counterclockwise rotation to outside the coronary ostium. This procedure should only be attempted if the artery is large enough to accommodate the guide, if there is no ostial or proximal lesion, and if the guide tip is soft.

*****Rotational amplatz maneuver for the RCA** To enhance the support role of a Judkins guide (active support or "power position"), the guide is torqued counterclockwise and simultaneously pushed down gently to make a loop in the coronary sinus in such a manner that it takes a 90° bend on its shaft. The original secondary curve is hence obliterated and, in fact, displaced proximally to obtain direct support from the opposite aortic valve. This maneuver is distinct from deep-seating of the guide, where no support is derived from the opposite aortic wall. This can be done with a small soft guide (6 Fr).

If the guide is stiff or has a smaller curve size, it will tend to prolapse into the ventricle with the wire pulled back into the aorta. Such a catastrophe can be avoided by carefully monitoring the shape and the position of the guide as the maneuver is carried out. Having rotated the guide in a counterclockwise direction while advancing it, it is essential to have the distal part of the guide on a plane parallel to the aortic valve. If the catheter moves downward, toward the aortic valve, further advancement will result in the prolapse of the guide into the ventricle. At that point, the guide should be gently pulled back and rotated further counterclockwise prior to its advancement. If prolapse tends to recur, this maneuver should be abandoned [9]. It is also very important to avoid excessive rotation that may lead to kinking of the guide and impede and/or dislodge stent passage. This maneuver is also not useful when a JR cannot engage the RCA because of an ostial lesion. However, an Amplatz or EBU guide could provide the same support without excessive manipulation of the guide and unexpected complications.

***Why do active support maneuvers work?** In general, clockwise rotation leads to deep engagement of the guide, and counterclockwise rotation leads to Amplatzing (both for left and right coronary arteries). The reason is that both left and right sinuses of Valsalva limit free movement of the guide shaft when it is turned clockwise, and rotation is transmitted linearly, leading to deep insertion into the artery. However, with counterclockwise rotation, because there is enough space from the non-coronary sinus, there is a possibility that the shaft will torque inside the non-coronary sinus and take support from the contralateral aortic wall.

GUIDE FOR SAPHENOUS VEIN GRAFT

Selection and manipulation of guides for SVG and internal mammary grafts are discussed in detail in Chapter 14.

CATHETERS FOR AORTIC ANEURYSM AND DISSECTIONS

When performing procedures on patients with an aneurysm in the ascending aorta, the technical problems could include a loss of catheter control or inadequate catheter length to reach the coronary arteries. In the case of aortic dissection, the arterial entry route chosen may not allow access to the true aortic lumen, in which case other risks include extending a dissection plane by advancement of the catheter or wire into the false lumen, perforation of the aorta by manipulation or injection in a false lumen, or displacement of thrombotic material from an aneurysm [10]. For these reasons, a careful discussion of the goals of angiography should be carried out with the surgeon. The role of aortic angiography is to visualize the origin and flow into coronary arteries. Many surgeons do not require extensive angiography when multislice computed tomography (MSCT) or magnetic resonance angiography (MRA) can better confirm the size and the extent of the dissection in the aortic arch, and the need for angiography can be avoided.

Tips and Tricks

****Simple maneuver to determine supra-aortic vessel involvement** When planning to perform angiography for a patient with suspected ascending aortic dissection, the difference in blood pressure between the two arms will pinpoint the involvement of the supra-aortic arch vessel. If the blood pressure in the right arm is higher than in the left arm, then there is a possibility of the dissection involving the left subclavian artery without involving (or distal to) the innominate artery, so the femoral, right radial, or brachial approach is preferable.

****Which approach is best for aortic dissection? radial or femoral?** In cases of aneurysm or dissection limited to the thoraco-abdominal aorta, the radial or brachial approach is preferred. When the CT scan shows involvement of great vessels or carotids, the radial or brachial approach should be avoided. When there is involvement of lower extremities, access from the involved limb is avoided. When extensive ascending and thoraco-abdominal aneurysmal disease is present, the femoral approach is chosen because of greater ease of catheter exchange and manipulation [10].

****Is the catheter in the true lumen?** In patients with aortic dissection requiring ascending aortography, an attempt is first made to enter the left ventricle directly with a pigtail catheter. After the pressure measurement is made, the catheter is pulled back and aortography is performed. In this way, one can be assured of being in the true aortic lumen. It is risky to attempt to cross the aortic valve against resistance. A straight-type catheter with a blunt tip, like the Sones or the MP, should be used cautiously in known or suspected aortic dissection due to the possibility of advancing it into the false lumen [10]. Since most of the dissection occurs in the lateral wall of the aorta, the pigtail catheter can be positioned in the true lumen by advancing it while hugging the medial aspect of the aortic arch in a shallow AP view. In the true lumen, selective cannulation of the coronary artery is possible, as is a direct entry into the LV.

****Ascending aortogram** An ascending aortogram in the LAO projection is obtained with 45–60 mL of contrast with a flow rate of 15–20 mL per second. The aortogram is frequently helpful in defining the shape and size of the aorta, showing the position and orientation of the coronary ostia, and choosing appropriate coronary catheters. Injection is never made if the aortic pressure is damped or there is no brisk blood return through the catheter. If the test injection shows delayed washout or swirling of contrast, it is assumed that the catheter is in the false lumen. It is withdrawn and redirected into the true lumen with a 0.035-inch high-torque floppy wire [10].

****Engagement of the coronary catheter** When the aortic root is horizontal, the JL 6 catheter is often successful in cannulating the LM. Most often it must be "pulled into" the LM by a combination of advancement of the catheter below the ostium with simultaneous retraction of the wire, which is curled up into the left sinus. Due to the frequent prolapse of the catheter, this maneuver often needs to be repeated many times before successful engagement is achieved. Thus a 0.038-inch wire is inserted through the Y adapter and left ready in the catheter so the maneuver can be repeated quickly if needed. When the aortic root is vertical, the Amplatz left 4 is more frequently successful in engaging the LM. The catheter is engaged by curling the wire well up the left sinus and tracking the guide up just below the LM. The wire is then retracted, and the guide is gently advanced up into the LM [10].

Engagement of the RCA is frequently problematic because its origin is often distorted. Usually, it is displaced low in the floor of the right sinus of Valsalva (SoV) (particularly in a horizontal root), but its origin may occasionally be abnormally high. In many cases, the dissecting plane begins above the RCA. Therefore, the aortic diameter may be normal at the level of the RCA, which is usually easily engaged with the standard JR 4 or 5 catheters [10]. In contrast to the patient with an aneurysm, the aorta diameter in dissection may be narrower due to systolic compression of the true lumen by the hematoma. One problem is a lack of support from the dissecting aortic wall to the Judkins catheter. Amplatz catheters require support from the aortic valve cups for manipulation, and, due to the weakening of the aortic apparatus by the dissection, the catheters are more difficult to use, prolapsing frequently into the left ventricle [10].

GUIDES FOR CORONARY ANOMALIES

Regardless of their rarity, an experienced interventionist should be aware of mostly all variations of coronary anomalies and systematically search in other aortic sinuses when the vessel in question does not arise from its usual location. For PCI, the location of the ostium of the anomalous artery and the geometry of the proximal segment should be the prime determinants dictating the selection of a specific guide. An RCA with a long horizontal segment in the LAO view may appear to have an angle of proximal vessel orientation favorable for the use of a Judkins curve, but the long segment usually represents an ectopic origin, appreciated more readily in the RAO projection. Coaxial engagement of these arteries may be more difficult and require considerable manipulation. To cannulate the anomalous artery from the right sinus, the best guides are the left and right Amplatz and MP guides. For the artery originating from the left sinus, the best guides are the larger JL, AL, and MP guides. In some very unusual anomalies, "trial and error" guides selection, or reshaping of guides may be necessary [11]. Approach from the radial artery may offer a better chance of success.

WARNING

Anatomic Anomalies at the Ostial Segment

Not every anomaly has a wide ostium that the tip of the guide can hook onto or a narrowing at the opening that needs to be stented. An anomalous RCA from the left sinus or the LM from the right sinus can leave the aorta in an oblique fashion, so the ostium has a slit-like configuration formed by flaps of aortic and coronary tissues. During exercise, the aorta can expand its part of the flap, further narrowing the slit-like opening and causing ischemia [12]. It is generally advisable before intervention to start with aortography in the LAO and RAO projections to obtain a clear view of ostial positioning, which saves time and decreases the risks of unnecessary maneuvering for cannulation.

Tips and Tricks

*****Guides for right aortic arch** In patients with right aortic arch, dextrocardia, or corrected transposition of situs inversus, a left coronary catheter may be used to cannulate any artery originating from the right aortic sinus. A right coronary catheter will be used for an artery originating from the left sinus. The catheter is torqued in a counterclockwise fashion rather than the usual clockwise one and is based on mirror-image angles.

*****Guides for anomalous coronary arteries arising above the sinotubular ridge in the ascending aorta** Patients can have coronary arteries arising above the sinotubular ridge. In this situation, the best guide would be an Amplatz-type guide. An MP guide could help if the ostium is not situated too high [13].

*****Guides for anomalous coronary arteries arising from the left sinus** When the RCA arises from the left cusp, it is usually anterior and cephalad to the LM, so in principle it can also be cannulated by a JL guide with the secondary curve one size larger than the one used for the patient's LM. This larger Judkins should be pushed deep in the left SoV while making a small counterclockwise rotation, causing the tip to make an anterior and cephalad-pointing U-turn. The EBU guide is also useful because of its preshaped configuration. The larger curve will prevent the guide from engaging the patient's LM [14]. By the same principle, an AL 2 with a tip pointed more anteriorly would help to cannulate the artery by being torqued counterclockwise while being pushed gently [14]. Others report the use of a JL 4 with an eccentric tip to cannulate the anomalous RCA from the left sinus. The primary curve of the type G catheter is out of plane to the remainder of the catheter in an anterior orientation, thereby avoiding the normal left coronary ostium [14].

*****Guides for anomalous coronary arteries arising from the right sinus** The anomalous artery usually arises from the very proximal RCA or a separate orifice in the right cusp. The most frequent variant is an LCX arising from the RCA or right SoV. It appears anteriorly and inferiorly. An Amplatz left guide is well suited for cannulating this vessel and will do so selectively rather than entering the RCA. When the JR cannot provide a stable platform to advance the hardware, an Amplatz right (AR) can cannulate the ostium easily [15]. When the origin of the artery is at the base of the aortic sinus, deep engagement of the guide is key. Contralateral wall support is not always feasible due to the downward orientation of the ostium. An MP or Amplatz left 1 or 0.75 guide should be used in this situation. These "anteriorly displaced RCAs" could not be visualized with conventional right coronary catheters and were selectively imaged with an Amplatz left 0.75–1 in 80% of cases and an Amplatz right 2 in 20% of cases [16].

*****Guide for coronary arteries arising from the posterior sinus** The most common anomaly is an anomalous LCX originating from the right sinus. A JR 4 can cannulate the artery by torquing the guide clockwise so that its tip points more posteriorly, working in an RAO projection. An AL guide can also be cannulated, and its tip should be oriented posteriorly by torquing clockwise to successfully engage the ostium of the anomalous LCX [16].

****Guide for missing arteries** When there is a missing LCX or RCA, possible abnormal locations are suggested in Table 4.3. A few guidelines with guide selection may help to pinpoint where the missing arteries might be and their ostia to be engaged. A good starting point is to perform aortography in the LAO and RAO, which saves time, fluoroscopy, and contrast.

***** Guides for the ectopic RCA from the anterior half of the left sinus** In all of these cases, the ectopic RCA originated from the anterior half of the left cusp, either anteriorly or superiorly to the LM. A wide variety of diagnostic and interventional catheters were used to selectively image these arteries, including MP 1–2 (50%), EBU (37.5%), and Amplatz left 2–3 (12.5%).

Step 1. After failing to selectively image the RCA with conventional RCA diagnostic catheters, perform a right sinus injection in the LAO 30–40° projection (or biplane imaging when

Table 4.3 Guides for missing arteries

Missing arteries	Guide selection
Missing LCX due to very short LM	Use a large guide with a short tip and turn clockwise to point the tip more posteriorly
Missing LCX originating from RCA	Guide with short tip Amplatz left, pointing anterosuperior to the RCA ostium
RCA in left sinus	Judkins left one side larger, pointing anterosuperior to the LM ostium
No LM	In the right sinus, Amplatz left guide pointing anterosuperior to the RCA ostium

available). This injection should delineate the RCAs originating from the posterior two-thirds of the right sinus and will provide information regarding the takeoff and orientation of these RCAs. If the RCA cannot be visualized at all, proceed to Stage 2.

Step 2. Use an Amplatz left 0.75–1 (depending on the size of the aorta), and in the RAO projection 30–40°, with the catheter pointing anteriorly and slightly caudal, attempt to image the RCA originating from the anterior third of the right coronary sinus (also known as an "anteriorly displaced RCA"). If subselective injections fail to image the RCA at this location, it is very likely that the RCA originates from the anterior half of the left sinus.

Step 3. Using the same Amplatz left 1 in the AP view, locate the LM. Turn the catheter counterclockwise in order to twist the tip anteriorly, and then push forward to advance the tip higher. The ostium of the RCA is suspected to be anterior and cephalad to the LM.

Step 4. If the RCA cannot be seen, repeat the injection above the left coronary ostium to image the ectopic RCA with a higher left sinus takeoff [15].

MANIPULATION OF GUIDE DURING PCI

GAME PLAN

Which Technique Is Best in Stabilizing a Guide?

In order to advance interventional devices to the intended position, a guide needs to give enough backup support. Three factors were found to be associated with increased backup of a guide.

1. The first factor is the size of the guide, i.e. diameter (larger is stronger if the same material has been used in the construction of the shaft).
2. The second factor is the angle between the wall of the ascending aorta and the segment of the guide spanning the aortic root. This segment is the long tip of the EBU, MP, or Amplatz guide, or the segment between the primary and secondary curve in the JL guide. The maximal angle is 90° (perpendicular to the opposite wall of the ascending aorta). In a relaxed position, the backup force of a JL is weak. However, as the guide is deep-seated, this angle changes and becomes bigger, so the backup force is greater.
3. The third factor is the aortic wall area on which the secondary curve of the guide rests: the larger the area, the firmer the backup (up to 25 cm).

In all three criteria, the EBU guide fares the best. The Amplatz design shows a very long line resting on the opposite wall of the ascending aorta, and this is the mechanism of the strong backup of the Amplatz left. In summary, the guide size, the angle between the guide and the ascending aorta, and the contact area between the ascending aortic wall and the guide have been found to be associated with increased backup force.

Real-time Actions

Navigating coronary artery anomalies requires specialized knowledge in catheter selection, angiographic views, and treatment strategies. For separate ostia of the LAD and LCX, a smaller catheter for the LAD and a counterclockwise maneuver are recommended. Anomalous RCAs from the right cusp benefit from 3DRC or Amplatz catheters, while anomalous LCXs from the same cusp, a common benign anomaly, can be engaged using Amplatz or Judkins catheters, sometimes requiring a two-guidewire technique. In cases of anomalous RCA from the left sinus, Leya catheters are advised for origins near the LM, with Amplatz or Judkins catheters suitable for other locations. Posterior origins of the LM are best accessed with EBU guide and anomalous LMs from the right cusp often respond to Judkins or hockey stick catheters, with CT angiography being crucial for assessing the vessel's course. IVUS and fractional flow reserve (FFR) play a role in risk stratification, with IVUS revealing ostial morphology and FFR guiding treatment decisions, considering the dynamic nature of these lesions. Surgical intervention, such as unroofing, is recommended for symptomatic anomalous LMs with interarterial courses, while intraseptal anomalies and RCAs from the left cusp may warrant consideration for intervention due to potential ischemia or risk of sudden death.

Tips and Tricks

*****Difficult engagement of a guide despite easy engagement by a diagnostic catheter** Sometimes a diagnostic catheter can engage an artery easily, but it is very difficult with an interventional guide. After the diagnostic catheter engages the artery, a long 0.014-inch wire is advanced into the artery, and then the diagnostic catheter is replaced with the guide. In a similar situation, when there is difficulty in deeply engaging a guide, a 0.014-inch wire is advanced into the artery and used as a rail for tracking the guide. A wire with a gradual tip transition should be selected to avoid prolapsing at its point of transition and disengagement of the guide.

****Deep-seating maneuver** To provide further support for an interventional device to cross a tight lesion, some operators suggest deeply engaging the tip of the guide into the ostium. For the RCA, the interventional device is retracted as the guide is advanced over the wire and gently rotated clockwise. For the LAD, counterclockwise rotation while advancing the guide provides the best deep seating. To point the guide toward the LCX, clockwise rotation is suggested (Box 4.2).

****Stabilizing a guide with the "buddy" wire technique** When working with an unstable guide, after unsuccessful advancement of interventional hardware, a second angioplasty wire can be advanced parallel to the first one. It straightens the tortuous vessel and provides better support for device tracking. A second wire in a side branch can be very useful in "anchoring" the guide (e.g. a second wire in the LCX when dilating an LAD lesion). This provides for better "backup" and allows retraction of the guide when necessary, without loss of position. It also prevents the guide from being "sucked in" beyond the LM when pulling back high-profile, poorly rewrapped balloon catheters following stent deployments or post-stent dilations. However, a second wire in a non-diseased branch would cause unnecessary denudation of endothelium in that vessel.

If one extra wire does not help, two or three buddy wires may help to advance any devices.

*****Stabilizing a guide with an anchoring balloon** When working with an unstable guide, a second small balloon (1.5–2.5 mm diameter) can be inserted in a small proximal branch and inflated at 2–5 atm to anchor the guide (without letting the guide back out).

*****Stabilizing a guide with a long sheath** When working with an unstable guide, a long sheath can stiffen and support the guide, depending on how close it is to the tip of the guide. The closer it is, the more supportive the system becomes. At first, the sheath tip is positioned high in the ascending aorta. If further backup is required, the sheath can be advanced further. As the sheath advances over the guide, it straightens the secondary and tertiary curves of the latter, causing the tip of the guide to move forward. Therefore, guides with relatively simple curves (Amplatz, MP, EBU) are probably safer and better suited for this technique. To avoid proximal coronary dissection, instead of fixing the guide in place as the sheath is advanced, gentle reverse traction on it is advised so that the guide tip does not move forward. The operator should watch the guide tip continuously on fluoroscopy during this maneuver and should ensure the guide is coaxial in two orthogonal views. Also, disengaging the guide from the coronary ostium should be performed only after the sheath has been retracted away from it, probably to the descending aorta, with the guide fixed in place. After PCI, it is possible that by just pulling the sheath away from the ostium, the guide will disengage because of reconstitution of its curves. A larger-diameter sheath can be used if even more support is deemed necessary. The sheath size can be selected depending on the amount of support needed (a larger Fr size will give more support) and the height of the patient (taller patients will require longer sheaths) [8].

*****How to extend the tip of a guide** In an extremely enlarged aorta, the tip of a guide can be extended with the help of a catheter. First, a coronary guide with a large bend, usually the Amplatz left, is advanced into the ascending aorta. A 6-Fr size is sufficient since the inner lumen is 0.070 inch (1.78 mm). Inside this guide, a longer (125-cm) 5-Fr MP catheter (internal diameter 0.058-inch, MP A1) is advanced. The 5-Fr catheter is longer than the guide and can serve as an extended tip to the 6-Fr guide. The inner catheter can be rotated independently of the guide, and thus it is possible to adjust the orientation of the system and deeply intubate the coronary arteries [8].

*****Strengthening the guide with another guide or catheter** To stabilize a guide, a 5-Fr Heartrail™ (Heart Rail II, Terumo, Tokyo, Japan) straight catheter 120 cm in length can be inserted inside a 6-Fr guide (100 cm long). The 5-Fr Heartrail catheter has a very soft 13-cm end portion. This soft end portion can easily negotiate the tortuous coronary artery with minimal damage and can then be inserted more deeply into the artery. The inner lumen of the 5-Fr Heartrail catheter is 0.059 inch in diameter; it can accept normal balloons or stent delivery systems less than 4.0 mm in diameter. The inner lumen of the outer 6-Fr catheter needs to be more than 0.071 inch in diameter to accommodate the 5-Fr Heartrail catheter [17].

Real-time Actions

5-in-6 Guide strengthening When a lesion cannot be crossed by a balloon or a stent in the regular 6-Fr system, the 5-in-6 system can be tried ("mother-in-child"). First, the balloon or the stent is removed from the 6-Fr guide, while the wire and the 6-Fr guide remain in place. Next, a 5-Fr guide is inserted over the wire inside the 6-Fr guide. At this point, the 5-Fr guide should not protrude out of the tip of the 6-Fr guide. Finally, the Y-connector is connected to the 5-Fr guide, and PCI can be restarted. Before the 5-Fr guide is advanced into the target artery, a balloon catheter is advanced near the target lesion in the artery. Keeping a slight tension on the balloon catheter, the 5-Fr guide is pushed out slowly in order to avoid possible injury to the coronary artery by the tip of the 5-Fr guide [8].

Tips and Tricks

****Insertion of the guideliner** The GuideLiner™ (Vascular Solutions, Minneapolis, MN, USA) is a flexible catheter that is 1-Fr size smaller than the guide; it is delivered through the guide. It has a rapid-exchange design and is advanced over standard-length wires, with a monorail length of 20 cm and a working length of 135 cm. The GuideLiner extends beyond the guide and is seated deeply in the coronary artery, allowing support and coaxial alignment for the advancement of wires, balloons, and stents during coronary interventions. It also allows coaxial alignment when an unusual coronary ostium takeoff prevents appropriate guide engagement. While the rapid exchange extension is 20 cm long, a maximum extension of only 10 cm beyond the guide tip is recommended and has a silicone coating for lubricity. When inserting the GuideLiner into the guide, the flat push-tube should be oriented in a lateral

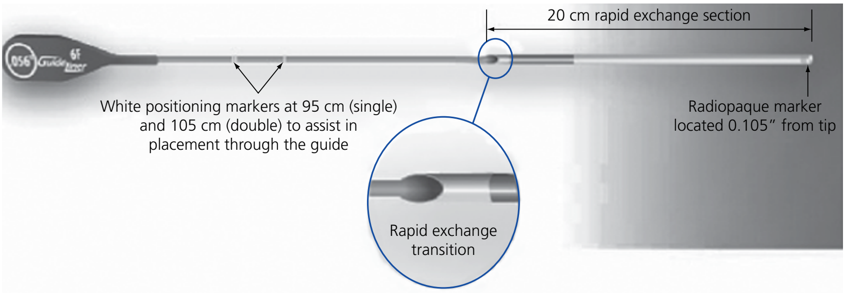

20 cm rapid exchange section
White positioning markers at 95 cm (single) and 105 cm (double) to assist in placement through the guide
Radiopaque marker located 0.105" from tip
Rapid exchange transition
056 GuideLiner 6F

Figure 4.12 The GuideLiner catheter.

position and should be further advanced without rotation to avoid wrapping of the wire [18] (Figure 4.12).

****Balloon-assisted deep insertion of the guideliner** Deep-vessel engagement by the GuideLiner can be facilitated by passage of a balloon catheter over the primary wire into the distal vessel, followed by low-pressure balloon inflation. This acts as an anchor to support gentle advancement of the GuideLiner [19].

****Advancement of stent through the guideliner** Stents should be advanced through the GuideLiner over the primary wire, as secondary wires may wrap around the GuideLiner and obstruct stent insertion. In cases of resistance while inserting a wire or stent through the GuideLiner, the location of the wire or stent in relation to the metal collar of the GuideLiner should be checked, and the stent inspected for signs of damage prior to readvancement. To correct any resistance that occurs at (or proximal to) the collar:

1. If a secondary wire is in use, check for wrapping of the secondary wire around the GuideLiner. If wire wrap is evident, consider pulling back the secondary wire and readvancing it. Alternatively, if the primary wire is still in place, consider advancing the stent over the primary wire [19].
2. If a stent continues to encounter resistance at the metal collar, pull the stent and wire back together 3–5 cm and try readvancing the stent and wire together through the metal collar. If resistance is again encountered, check the stent for signs of damage and either choose a lower-profile stent or change the wire.

****Advantages and limitations when advancing a stent through the guideliner** One limitation is the small risk that large or bulky stents can be damaged entering the collar, so the use of low-profile stents is recommended with this system, avoiding stents >4 mm in diameter. In case of resistance while inserting a stent through the GuideLiner catheter, the location of the device in relation to the metal collar should be checked and the stent checked for damage. Even a low-profile stent 2.25 mm in diameter has been damaged. The reason is that the stent may get stuck at the metallic collar if it coincides with a bend in the catheter. Gentle retrieval of the GuideLiner so as to place the collar in a straighter segment of the guide helps to get the stent into the catheter extension.

The second limitation of the GuideLiner is that to treat a proximal posterior descending artery (PDA) with a 6-Fr JR guide, the GuideLiner could be advanced over the wire into the acute margin of the RCA, but the support was not great enough to cross the lesion with a balloon. Deeper intubation could have been achieved if a balloon had been inflated distally, using it as an anchor to further advance the GuideLiner. Proximal dissection may occur after positioning the GuideLiner deeply or during forceful injection of contrast [20].

DEDICATED EQUIPMENT

E

The Heartrail II Catheter

This is a 120-cm 5-Fr soft straight-tipped catheter, which is delivered within a standard 6-Fr coronary guide. Up to 13 cm of this 5-Fr catheter may extend beyond the coronary guide, allowing deep engagement of the target coronary artery in an atraumatic fashion. This facilitates delivery of intracoronary devices, especially stents, and is particularly useful where tortuous coronary anatomy exists.

The Heartrail "5-in-6" system involves insertion of an extra-length 5-Fr soft-tipped catheter into a standard 6-Fr guide so that the distal tip of the 5-Fr catheter can extend or "telescope" up to 16 cm beyond the tip of the 6-Fr catheter. The hemostatic valve is disconnected from the guide once the guide and coronary wire are in position [18].

Advantages and limitations The initial setup can take more time, and suboptimal opacification of the coronary artery can occur. This highlights the importance of compiling detailed angiograms prior to proceeding with this device to comprehensively delineate the target lesion(s). The operator must be aware of possible anatomic distortion of the artery with delivery of the 5-Fr catheter, similar to the effect seen with stiff wires. Another danger is the risk of air entrainment leading to air embolism, and careful back-bleeding is mandatory before injection. Finally, particular care is required when advancing the Heartrail to avoid inducing a dissection [19].

BEST TECHNIQUE IN STRENGTHENING A GUIDE

1. $ FIRST Best maneuver: Add a second, stiffer wire
2. $ ⌛ SECOND Best maneuver: Change to a stronger guide
3. $$ ⌛ 💧 THIRD Best maneuver: Advance a small balloon to a side branch and inflate the balloon to prevent the guide from backing out
4. $⌛ Change the current sheath to a very long sheath
5. $⌛ Double-guide technique: insert a smaller guide in the current guide

Tips and Tricks

****Changing a guide with wire across lesion (Japanese blowing technique)** Changing a guide is more difficult if the lesion has already been crossed by a wire. If wire placement was difficult, it is desirable not to recross the lesion. Techniques have been developed to allow the exchange of guides over regular-length angioplasty wires. The use of exchange wires with long radiopaque tips facilitates this procedure by minimizing the chance of failing to notice a redundant loop of radiolucent wire in the aortic root.

Real-time Actions

Exchange of a guide without removing the wire If the operator is working on regular-length wire, it is advisable to insert a microcatheter or over-the-wire balloon and to exchange the wire with a 300-cm one. Next, remove the balloon or microcatheter to ensure enough space for free consecutive movement. First, withdraw the guide a few centimeters without losing the position of the wire across the lesion. When the proximal end of the guide meets the proximal end of the wire, attach a syringe full of fluid to the guide. Under fluoroscopy, withdraw the guide while keeping the wire immobile by continuing to inject the fluid into the guide from the syringe. With this, the guide is removed slowly. Once the guide is out of the sheath, the new guide is inserted over the two wires: the angioplasty wire across the lesion and a 0.035-inch wire. When the guide is at the ascending aorta level, the 0.035-inch wire is removed. A balloon catheter with a very small size (1.25 × 10 mm or 1.5 × 10 mm) is inserted as far as possible to provide a good rail for guide insertion. Once the balloon catheter is at the ostium of the coronary artery, the new guide is then advanced over the shaft of the balloon catheter, which can provide a better rail for the guide than the wire alone would.

TACTICAL MOVE

BEST Technique for Changing a Guide with Wire Across Lesion

1. **$⧖ FIRST Best technique for American operators:** Change the guide through the extension of the existing angioplasty wire
2. **No extra cost. FIRST Best technique for European and Asian operators:** Remove the guide while injecting contrast from a syringe and insert the new guide through a second stiff 0.035-inch wire while the angioplasty wire is kept immobile across the lesion. Reinsert the guide through a balloon catheter
3. **$⧖⧖ Third option:** Remove the whole system, change the guide, and recross the lesion

Tips and Tricks

****How to untwist a twisted guide** When the iliac artery is very tortuous, a torquing maneuver can twist the guide at its proximal segment. Usually, the pressure curve will disappear on the screen. The patient may complain of pain in the lower quadrant area because when the guide becomes twisted, it forms a sharp bend pointing laterally and can perforate the iliac artery. On seeing a twisted guide, the first thing to do is to move the twisted segment to a large area by advancing it into the aorta rather than leaving it in the iliac artery. Then cannulate the guide with a 0.035-inch wire and move its tip to the twisted area. Next, try to untwist the guide by torquing in the opposite direction. If you turned the guide more clockwise in the last few minutes, try counterclockwise now (or vice versa): work on a trial-and-error basis. However, as you torque, slowly advance the wire to secure the segment you just untwisted. If you see on fluoroscopy that the guide has become more tortuous, that means you are making the situation worse. Try the opposite direction. Advance the wire gently as you torque. In a matter of less than 1 or 2 minutes, the damaged guide should be disentangled, straightened, and removed.

****How to untwist a twisted guide in the brachial artery** After numerous unsuccessful attempts to engage the RCA by clockwise rotation and catheter advancement, abrupt damping of the arterial wave was observed together with the inability to further manipulate the catheter. Fluoroscopy showed that the JR4 catheter was severely looped and kinked on itself in the brachial segment (Figure 4.13). Counterclockwise rotation failed to de-loop the catheter, and no wire, including hydrophilic-coated coronary wires, could cross the kinked segment. Consequently, it was decided to attempt to recapture the kinked catheter percutaneously through the same arterial access using a sheathless guide.

First, a scalpel was used to cut the proximal part of the JR4 catheter (Figure 4.13a). Second, a 100-cm long 7.5-Fr power backup sheathless guide (Asahi, Seto, Aichi, Japan) was also shortened proximally by 60 cm using scissors. The kinked part of the JR4 catheter could be retrieved to 10 cm below the elbow, resulting in an external length of 50 cm. A 40-cm residual length of the sheathless guide would allow for recapturing the proximal tip of the JR4 catheter, which was mandatory for successful retrieval. Next, the 5-Fr 10-cm Infinity sheath (Cordis, Miami, FL, USA) was exchanged for the shortened 7.5-Fr sheathless guide over the 5-Fr JR4 catheter while keeping the 0.35-inch regular wire still inside the catheter (Figure 4.13b). Then the guide was gently advanced until the proximal part of the JR4 catheter could be visualized and was carefully held in a fixed position by the second operator (Figure 4.13c). Subsequently, the guide was further advanced up to the loop (Figure 4.13d), and, under fluoroscopy, the kinked diagnostic catheter was carefully pulled, smoothly unfolding its loop while slipping into the larger guide (Figure 4.13d,e). Hemostasis was achieved using a unilateral compression system (Terumo Medical Corporation, Somerset, NJ, USA).

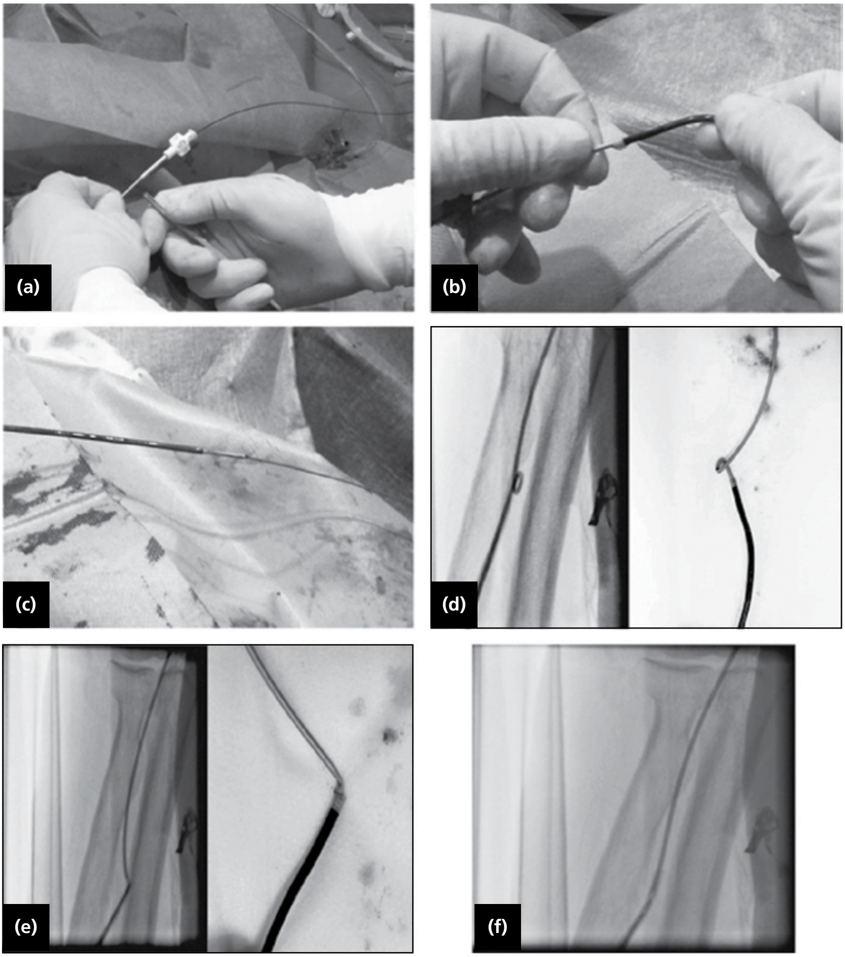


Figure 4.13 (a) The proximal part of the JR4 catheter was cut. (b) The shortened 7.5-Fr sheathless catheter was slipped over 5-Fr JR4 while keeping the 0.35 in regular wire still in the catheter. (c) The sheathless catheter was advanced until visualization of the proximal part of the JR4 catheter, which was carefully held in a fixed position. (d) The sheathless catheter was further advanced up to the loop. (e and f) Under fluoroscopy, the kinked catheter was carefully pulled and smoothly unfolded its loop while slipping into the sheathless catheter. Source: Reproduced with permission from [20] / John Wiley & Sons.

CORONARY ACCESS AFTER TRANSCATHETER AORTIC VALVE REPLACEMENT

CHALLENGES

Transcatheter aortic valve replacement (TAVR) has become a standard therapeutic option for patients with aortic stenosis. However, coronary access following TAVR during CAG or PCI remains a complex procedural challenge. This is especially true in the context of self-expanding valves, supra-annular leaflet positioning, and valve-in-valve (ViV) procedures. Several anatomical, device-related, and procedural factors contribute to these difficulties, with commissural misalignment, SoV dimensions, and transcatheter heart valve (THV) design playing central roles. Which tactics and technical manipulations facilitate safe and effective coronary access after TAVR?

WARNING

The feasibility of post-TAVR coronary access is influenced by the spatial relationship between the THV frame and the coronary ostia. Specific concerns include (1) the depth and orientation of THV commissures in relation to native coronary ostia; (2) the proximity of the valve frame to the aortic wall; (3) the location and orientation of bioprosthetic leaflets; and (4) the sino-tubular junction (STJ) dimensions (21).

Game Play

***Pre-procedural computer tomography analysis is essential** A comprehensive multidetector CT scan should be performed to evaluate coronary ostia height, SoV width, STJ dimensions, and commissural alignment. These parameters are critical for anticipating coronary access difficulties, particularly in ViV settings.

***Commissural alignment** Particularly problematic is the commissural overlap between THVs and coronary ostia, which can obstruct selective cannulation. When commissural posts align in front of the coronary ostia, they may physically impede catheter engagement. Commissural alignment of the THV with the native commissures minimizes overlap between neo-commissures and coronary ostia, thereby preserving access pathways. Misalignment can obstruct ostial access and limit catheter maneuverability. Therefore, proper orientation before implantation is essential. However, current delivery systems offer limited control over commissural orientation.

*****THV with supra-annular prostheses** Device-specific characteristics significantly affect coronary re-access. Evolut™ R/PRO/PRO+ (Medtronic, Minneapolis, MN, USA) valves are repositionable, SE, supra-annular prostheses composed of a nitinol frame and porcine pericardial tissue leaflets. Their high commissural posts, small diamond-shaped cells, and sealing skirt (13–14 mm) designed to prevent paravalvular regurgitation contribute to challenging coronary cannulation, particularly if deployed too high or if the ostium of the coronary arteries is low-lying.

The ACURATE neo™ (Boston Scientific, Marlborough, MA) SE valve features open-cell architecture with three stabilization arches and supra-annular leaflets. Although it is not repositionable, its top-down release mechanism and open frame design provide relatively easier coronary access, especially in patients with small SoV or low coronary height. This device, however, still poses challenges if commissural alignment is not achieved. On May 28, 2025, Boston Scientific officially discontinued worldwide sales of its Acurate neo2 and Acurate Prime TAVR system (22).

***THVs with large, open frame cells** The SAPIEN 3 and SAPIEN 3 Ultra (Edwards Lifesciences, Irvine, CA, USA) are balloon-expandable intra-annular valves with large, open stent cells and a shorter frame height. These features facilitate post-TAVR coronary access by allowing catheter engagement from above the frame or through large upper-row stent cells. The shorter commissural height reduces the likelihood of obstructing the coronary ostia. As a result, catheter selection and access strategies do not require significant modification, especially in ViV TAVR (22).

*****Avoid excessive implantation depth** High implantation of the THV increases the chance that the valve skirt or commissural posts will overlap or obscure coronary ostia. A controlled deployment depth is necessary to balance valve function and future access.

*****Maintain TAV-to-aortic wall distance >3 mm** In ViV cases, a minimal TAV-to-aortic wall distance <3 mm – especially if the coronary ostium lies below the top of the neo-skirt – is associated with a significant obstruction risk. Pre-implant CT simulation should assess this.

***Assess the "crossing zone" width** A narrow stent strut spacing at the level where coronary catheters must traverse the frame (the "crossing zone")—especially <3 mm – is associated with difficult access. This should be quantified during CT planning.

*****Utilize CT-based simulation tools** Simulation platforms using pre-TAVR imaging allow for modeling coronary access scenarios and help identify patients at high risk of ostial obstruction, thus guiding device selection and procedural planning.

Tips and Tricks

***Choose the right guide and catheters** JL 3.5 catheters (femoral) or JL 3.0 catheters (radial) are commonly used. If engagement fails, semi-selective angiography may help guide attempts. In difficult cases, EBU catheters, coronary wires, or anchoring balloons can support cannulation. For RCA access, JR 4.0 is standard, with modifications such as larger catheters or AR types in wide SoV anatomies. If a commissural post obstructs access, a multipurpose or Ikari catheter may be necessary (Videos 4.4–4.7).

Video 4.4 The Judkins left catheter crossed the struts into the left main coronary artery.

Video 4.5 The Judkins left catheter crossed the struts into the left main, left anterior descending coronary artery.

Video 4.6 The Judkins right catheter filled the right coronary artery with contrast without entering the artery.

Video 4.7 The Judkins right catheter injected the contrast to the base made by the aortic valve which reflected the contrast into the right coronary artery.

Cannulation through a diamond directly in front of the coronary ostium is preferred to maintain coaxial alignment. Accessing from below the ostium may cause catheter kinking or entrapment. Therefore, understanding the 3D THV-ostium interface is vital.

**** Consider guide extension catheters** Devices such as GuideLiner (Teleflex, Wayne, PA, USA) or Telescope (Medtronic, Dublin, Ireland) can assist in deep intubation beyond the THV frame, especially when the ostium is eccentrically located or partially covered by the valve structure.

****Use a wire-assisted technique** Placing a coronary wire across the stent struts and into the coronary artery before advancing the guide or catheter can facilitate cannulation in difficult geometries.

*****Apply a balloon-assisted tracking technique** In certain scenarios, advancing a deflated balloon into the coronary artery over a wire can help direct the catheter through obstructive struts into the coronary ostium.

*****Use the “snorkel” or “chimney” techniques only if necessary** In emergent situations where coronary access is lost, placing a stent extending from the coronary ostium into the ascending aorta (chimney) may preserve patency. However, these are bail-out techniques and are not yet suitable in standard practice.

*****BASILICA has limited role in TAVI-in-TAVI** While the Bioprosthetic or Native Aortic Scallop Intentional Laceration (BASILICA) technique shows promise in preventing coronary obstruction in native valve settings, it has limited effectiveness in TAVI-in-TAVI, especially with newer-generation devices. Effective leaflet splay is hard to achieve, particularly in SAPIEN 3 or Evolut R/PRO.

CONCLUSION

Coronary access after TAVR, especially in the setting of ViV interventions, presents complex anatomic and device-related challenges. Understanding the interplay of commissural alignment, stent frame architecture, THV selection, implantation depth, and CT-derived anatomical landmarks is critical. Through pre-procedural planning, procedural vigilance, and device-specific strategies, interventional cardiologists can significantly improve the likelihood of successful post-TAVR coronary engagement. These tips and tricks should guide both preventive and salvage strategies in preserving coronary access across the patient’s continuum of care.

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CHAPTER 5

Wires

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*Basic; **Advanced; ***Rare, exotic, or investigational

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💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

A wire consists of two main components: (1) a central shaft of stainless steel or nitinol and (2) a distal flexible tip shaped as a spring coil made of platinum or tungsten. Depending on their construction, core material, and diameter at the tip, wires have different properties that can be used in different situations. To advance a wire across the lesion and position the tip distally on a timely basis are the challenges during any interventional procedure.

ENGINEERING EVALUATION OF A WIRE

Steerability is the ability and responsiveness of the wire tip to navigate vessels. If the tip is flexible, and not too rigid, the wire can be steered through tortuous curves. **Trackability** is the ability of the device to track over a wire, especially around bends. This feature is determined by the lateral support provided by the wire. A longer, gradual taper of the core facilitates tracking but provides less support. On the opposite side, the shorter the taper, the greater **support** the wire has (because the force generated by the operator's hand can be transmitted to the tip). If the taper is short, the wire can turn around a bend; however, the segment around the bend is too short to hold the wire stable so the wire is more susceptible to prolapse. An example is a wire with a short taper prolapsing into the left anterior descending (LAD) artery when turning around the curve from the left main (LM) into the left circumflex (LCX).

Torquability is the ability to transmit torque from the proximal end to the distal end of the wire. In lay terms, torquability is the response of the wire to turning by the rotation of the proximal end of the wire by the operator. This property is important when navigating tortuous vessels or in drilling strategy where the wire is rotated in a controlled manner to search for the path of least resistance during percutaneous coronary intervention (PCI) for chronic total occlusion (CTO). Torquability depends on:

1. single-core wire – force transmission is not dampened by the flexible terminal coil
2. lateral support provided by the wire
3. specially designed wires capable of torque transmission (wires with dual or composite cores).

In general, flexible wires are less steerable, and stiffer wires offer more torque control [1].

Bending: the ability to bend is required to circumvent very stiff tissue, e.g. calcium. A coil structure at the end of the wire allows for this property whereas single-core wire resists it. **Lubricity** is the ease of passage against resistance encountered while moving the wire in a vessel or through any lesion. The resistance encountered depends on:

1. the tissue encountered: vessel lumen < micro-channel < lipid plaque < proteoglycan < collagen/elastin
2. bends (tortuous lesions)
3. length of the lesion.

In general, resistance varies according to the coating of a wire: polymer coat < hydrophilic < hydrophobic < non-coated. **Penetrability** is the ability to puncture a lesion such as a CTO; the stiffer the lesion, the more penetrability is required. Penetrability depends on:

1. tip load
2. tapered tip
3. wire support (microcatheter/over-the-wire [OTW] balloon, anchoring techniques, child-in-mother catheter)
4. lateral support of the wire.

Pushability is the amount of force needed to advance the wire or the ease of advancing the wire once it has penetrated a lesion. Pushability depends on (1) the characteristics of the tissue a wire has to traverse and (2) the length of the tissue to be traversed along the CTO and the lateral support provided by the wire.

BEST PLAYERS

aka Standard of Excellence

The wire should be able to be advanced gently and passed smoothly through the proximal vessel segment and the stenotic lesion. Withdrawal and reorientation of the wire are required when buckling occurs. The tip of the wire should be placed as far distally as possible, so the stiff part of the wire is across the lesion where the stent or other interventional device is to be tracked.

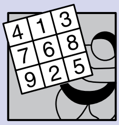
Discriminating Differences

Nitinol and stainless-steel wires Wires with a nitinol core are kink-resistant while those with a stainless-steel core are more susceptible to kinking. A core that extends to the distal tip provides better torque transmission and tactile feel. The nitinol core increases wire trackability, including the ability to traverse acute artery angulations without wire prolapse (the so-called "balanced force transmission"). Nitinol wire might be more capable of entering a retroflexed circumflex takeoff than a stainless-steel core wire. The limitation of nitinol core wire is that it tends to store rather than to transmit and torque [1].

Hydrophilic wires These hydrophilic wires are flexible and kink-resistant, featuring a hydrophilic polyurethane coating. Their core is made of a super-elastic titanium–nickel alloy, providing exceptional flexibility and resistance to kinking, which enhances pushability. A hydrophilic polymer coating results in low thrombogenicity and extreme lubricity when wet [1], Hydrophilic, polymer-coated wires, such as the ChoICE™ PT (Boston Scientific/Scimed, Inc., Maple Grove, MN), Asahi Prowater® (Abbott Vascular, part of Abbott Laboratories; Abbott Park, IL), Whisper® (Abbott Vascular, part of Abbott Laboratories; Abbott Park, IL), and Runthrough® (Terumo, Shibuya, Tokyo, Japan), have low friction and may advance more easily through tortuosity but may also carry a higher risk of dissection or perforation, especially if they select a small branch. Soft delivery catheters, such as the transit catheter or the dual-lumen Twin-Pass catheter (TeleFlex, Wayne, PA, USA), can improve the steerability of the wire by decreasing friction at the proximal segment. The Venture™ deflectable-tip catheter (Velocimed, Minneapolis, MN) can help guide the wire through tortuous coronary segments but is likely more useful in large coronary arteries, similar to the Steer-It™ (St Jude, Minneapolis, MN) deflectable-tip wire.

Stiff wires Stiff wires can straighten the curved segment, change the vessel shape, and cause wrinkles or pseudolesions. Removing the stiff part of the wire while leaving the radiopaque flexible end across the pseudolesions, exchanging for a more flexible wire or a flexible transit catheter, or pulling the wire completely out would abolish these pseudolesions. Other disadvantages of a stiff wire include difficulty of tracking stents because of the wire bias inducing coronary spasm, obstruction of flow induced by vessel kinking, and wire buckling due to sharp transitions. In these situations, the wire should be exchanged, and the use of atherectomy devices should be avoided because of excessive wire bias.

GAME PLAN



The wire should be advanced gently and not forced or jammed blindly as it can disrupt plaque and cause thrombus formation and ultimately acute occlusion. Any bend in the body of the wire makes one-to-one (1,1) torquing of the tip impossible. More forceful but cautious pushing can be applied only during the opening of CTOs. Repeated rotation of 180° in clockwise and counterclockwise directions also seems to aid wire advancement and reduces sub-selection of unwanted small branches [1].

Avoid rotating the wire through 360°. This may result in entanglement with a second wire or fracture of the tip if it is caught in a small branch. The radius of the curve on the tip of the wire should match the diameter of the segment that needs to be crossed, especially if side branch (SB) entry is intended. The primary and secondary curves should have a diameter a little larger than the diameter of the segment that must be crossed. Double or triple bends can be useful if there are two different angulated segments to cross [1]. Bends can be acute or smooth. Acute bends are often maintained despite tortuosity and bends in the vessel. After crossing the lesion, acute bends tend to direct the wire into the SBs instead of going through the main vessel (MV). Smooth bends can be straightened by rotating the wire while wiring the vessel. A support catheter can also be sided to straighten unwanted bend in the tip of the wire.

The operator should keep in mind the space orientation of branches and direct the wire tip with minimal manipulation, minimizing endothelial trauma.

Wiring the LAD

The LAD artery typically has little tortuosity, so the wire transition point between the flexible tip and the more rigid body is usually not a major problem.

Wiring the LCX

For LCX artery interventions, the wire needs to pass the LM, turn into the LCX, and then move forward to cross the lesion. In many cases, it requires a broad secondary curve to successfully enter the LCX and a smaller primary curve to cross into the obtuse marginal (OM). Wires with a gradual transition from the body to the spring tip are preferred to avoid continuous prolapsing into the LAD [1]. Anomalies in origin of coronary artery can be very challenging to an interventional cardiologist. This is especially true in the clinical scenario of ST elevation myocardial infarction, and the vessel is thrombosed from the ostium complicating visualization of the LCX origin.

Video 5.1 Coronary angiogram in a patient with infero-posterior STEMI showed separate origin of LAD from the aorta with missing dominant circumflex artery.

Video 5.2 Nonselective angiogram shows thrombosed anomalous circumflex artery.

Video 5.3 The LAD wire was used to stabilize the JL 3.0 guide in the left coronary cusp without engaging the artery, and a second wire with double curve was used to free wire into circumflex artery with subtotal ostial thrombosis.

Video 5.4 Successful wiring of anomalous dominant circumflex artery with subtotal ostial thrombosis.

Wiring the RCA

When the origin of the right coronary artery (RCA) is relatively normal, a conventional soft wire with good steerability to avoid SBs is usually selected. When the RCA arises anteriorly, the wire sometimes may be required as an aid to guide ostial intubation. In this situation, wires with improved tip transition or soft hydrophilic wires are selected to avoid prolapsing at the point of transition and disengagement of the guide [1].

ADVANCING A WIRE

In order to enter a tortuous proximal LAD, the best view is the left anterior oblique (LAO) caudal view (spider view). Once the wire is far enough in the LAD, the angle is changed to the anterior–posterior (AP) cranial view so the wire can be moved to the mid- and then the distal LAD.

Tips and Tricks

****Directing the wire when navigating the LAD** When navigating the LAD, on the LAO caudal view, the wire should point to the right of the screen. The left is toward the diagonal. Once inside the proximal segment, the better view is the AP cranial view. Here the wire should move downward. Any stray to the left will point to the diagonal, and stray to the right will point to the septals. If the LAD is entered in the RAO cranial position and the wire is pointing downward, most likely it has entered the LCX. If the wire moves widely, then it may enter the ramus intermedius, which buckles with contraction of the left ventricle like the diagonals. Usually, it is worthwhile to place a little extra curve at the tip of the wire because there is more angulation at the takeoff of the LAD than is apparent in the RAO projection [1].

****Entering the LCX without the wire prolapsing** Sometimes it is difficult to curve a wire into a branch of a large artery (such as from the LM to the LCX, then to the OM) because of the short stem of the second main branch. Despite persistent manipulation, the wire keeps buckling under pressure and prolapsing into the main branch (LAD). The reason is the abrupt transition between the short tip and the main shaft (a sharp bifurcation of the LCX). There are many ways to solve this problem.

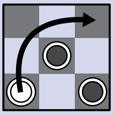
The first option is to deep-seat the guide so that the distance between the tip of the guide and the ostium of the LCX is shorter. The second option is to ask the patient to take a deep breath so that the heart is more elongated and the angle between the LCX and LM is less acute. During this short window of opportunity, advance the wire.

The next option is to change the current wire to one with a gradually tapered core so that as the tip is deeply advanced, it stabilizes the wire and the stiffer shaft can negotiate the angle better, without prolapsing into an unintended area (or the LAD) [1]. Once the soft part of the tip has passed the acute corner, torque the wire slowly while advancing it. The rotational energy will advance the wire distally. The tip of the wire needs to be curved, so that the length of the tip is a little longer than the diameter of the LM at the entry angle with the LCX.

Another option is to advance a small transport catheter into the proximal LCX. The new catheter prevents the buckling of the wire and helps the wire cross the tight lesion by shortening the distance between the tip of the catheter and the lesion, nullifying the acuteness of the angle between the LM and LCX [1]. The best maneuver ranking of each method in entering the LCX without prolapse of the wire is listed in Box 5.1.

****Crossing a coronary aneurysm with stenosis** A slit-like stenosis in combination with a coronary aneurysm is sometimes very challenging to cross. A soft wire with good torque control (balanced middleweight [BMW], Prowater, or Runthrough) or soft hydrophilic wire (Whisper) should be the first choice with a small primary curve to engage the slit-like stenosis and a large secondary curve to navigate the aneurysmal lumen) (Figure 5.1).

BOX 5.1 TACTICAL MOVE



BEST Maneuver for Entering the LCX without the Wire Prolapsing

1. **FIRST Best Maneuver**: Deep-seat the guide
2. **$. SECOND Best Maneuver**: Change the wire for one with a gradual tapered core tip
3. **THIRD Best Maneuver**: Ask patient to take a deep breath
4. **$$. FOURTH Best Maneuver**: Use a transport catheter

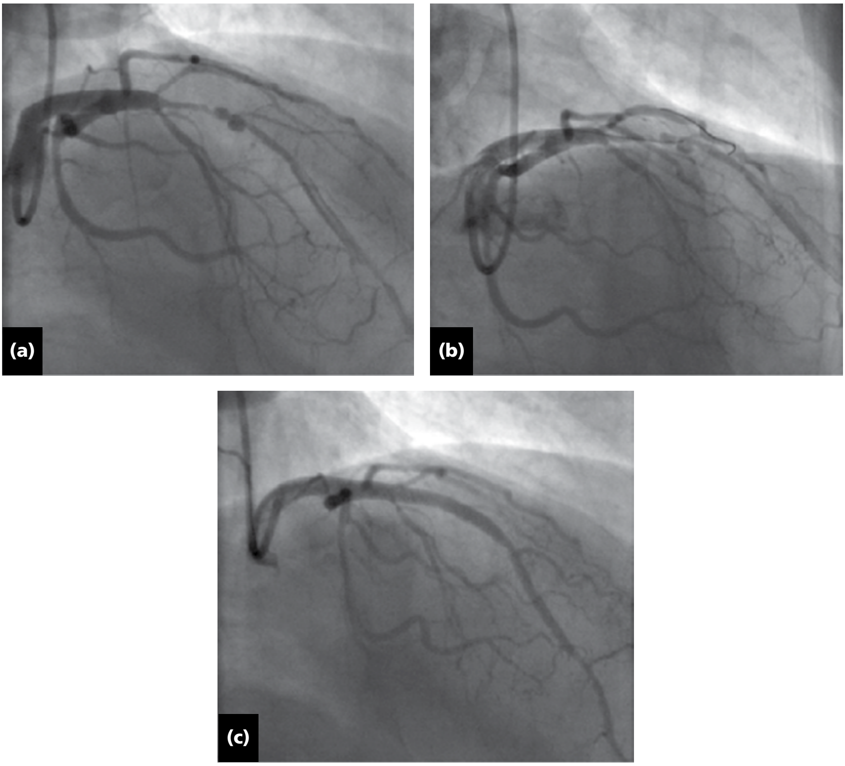


Figure 5.1 A bifurcation stenosis, Medina 011, with long main branch distal lesion finishing with aneurysm and slit-like highly eccentric stenosis; after several attempts, the lesion was crossed with a Whisper MS wire with small tip curve.

****Measuring the length of a lesion with a wire** It is not easy to guess accurately the length of a lesion if some segments are foreshortened because of tortuosity. When a vessel bends in more than one plane, no single angiographic view can overcome multiple foreshortenings. Most radiolucent wires have a 20–30-mm radiopaque distal end. Position this radiopaque segment across the lesion so the length of the lesion can be estimated. Another way to measure the lesion length is with a balloon that has markers at its two ends or using a marker wire.

****Pseudo-lesions** Use of a stiff coronary wire can potentially straighten the vessel tortuosity and facilitate stent delivery, but it can occasionally lead to excessive vessel kinking and development of coronary "pseudo-lesions," making stent delivery more difficult. When this occurs, the exchange of the wire with a softer wire or with a soft delivery catheter, such as the transit catheter, may result in resolution of the pseudolesions.

Placement of another wire may be facilitated by using a dual-lumen catheter: the twin-pass catheter has both a rapid-exchange distal lumen and an OTW lumen, is very soft and malleable, and can be used to introduce a second buddy wire or to exchange the existing wire without

BOX 5.2 TACTICAL MOVE

BEST Maneuver for Advancing a Wire Across Tortuous Segments

1. **FIRST Best Maneuver**: Select a hydrophilic wire
2. **SECOND Best Maneuver**: Advance a balloon near the tip of the wire
3. **THIRD Best Maneuver**: Advance a microcatheter to the tip of the wire

losing distal wire position. Sometimes, the use of a softer or 0.012-inch wire may be advantageous by causing less vessel deformation.

Advancing a Wire Through a Tortuous Segment

When the manipulation of a wire becomes difficult after it has passed through too many curves, there are many options to solve the problem. The first option includes the use of hydrophilic wires, which are very sleek and kink-resistant. However, because the hydrophilic wires are so smooth, the operator has little tactile feedback; they can easily go subintimal or cause distal perforation if inadvertently advanced into a small and short branch. So, when manipulating a hydrophilic wire, always watch the distal tip to avoid inadvertent migration and perforation. Probably, the best solution is to use a hybrid wire with a hydrophobic distal tip (distal 1–3 mm) and a hydrophilic body with a hybrid nitinol–stainless-steel core (Runthrough, BMW). Another option is to advance a balloon catheter near the wire tip in order to improve wire support, torque control, and steerability. Another (better, but more expensive) option is to use a soft microcatheter (Transit™ [Cordis Endovascular Systems, Miami Lakes, FL], Progreat® [Terumo, Japan], Finecross® [Terumo, Japan], or Corsair® [Asahi Intecc, Nagoya, Japan]), which has a softer and shorter tip (easy to advance) to improve the wire support, torque control, and steerability. A microcatheter also permits wire exchange with another wire. The best maneuver ranking of each method in advancing a wire across tortuous segment is listed in Box 5.2. In extremely tortuous vessels, you may have to advance the microcatheter to the middle of the vessel and exchange for a supportive wire like iron wire. This will straighten the tortuosity in the proximal portions of the vessel. Then, use a second wire to completely wire the distal vessel. Straightening the proximal vessel will allow torque and pushabilty in wiring the distal vessel.

Steering and Advancing a Wire Through a Severely Angulated Side Branch

In rare instances, a wire must enter a very acutely angulated SB. The first maneuver is to make a large-diameter curve at the tip, sometimes like a large hook, with a second shallow curve (1–2 cm) behind. A microcatheter can be introduced to decrease proximal friction of the wire and to facilitate its navigation. Using a stiffer or hydrophilic wire is helpful. If the wire cannot pass distally, it can be exchanged for a microcatheter to be introduced at the SB ostium. Then the entry wire is replaced with a soft wire (Whisper [Abbott Vascular, part of Abbott Laboratories; Abbott Park, Ill], Prowater, Runthrough). Another option is to use a double-lumen catheter (Crusade®) for support and wire direction. Other catheters that can help in wiring acute angulated vessels include dual lumen catheters Twin Pass, thrombectomy catheter, Enhancer, and ReCross catheters. More time and technical skills are required for the reverse wiring technique. The costliest options are to use the Venture control catheter or the Steer-It wire with a deflecting tip in order to position the wire exactly at the ostium of the SB. Multiple support catheters with preformed bends are also available in acutely angulated vessel (Box 5.3).

BOX 5.3 TACTICAL MOVE

BEST MANEUVER for side branch entry

1. **FIRST Best Maneuver**: Make a large primary curve more than 90° in the wire tip and second shallow curve (15°–30°) 1.5–2.0 cm behind (the length of the tip is equal to the diameter of the main vessel at the origin of the side branch)
2. **$$ SECOND Best Maneuver**: Advance a balloon or microcatheter near the tip of the wire
3. **$$ THIRD Best Maneuver**: Use a hydrophilic wire
4. **$$ Fourth Best Maneuver**: Use the wire with a deflectable tip – Steer-It
5. **$$$ Fifth Best Maneuver**: Use a double-lumen catheter to point the tip to the side branch
6. **Sixth Best Maneuver**: Use the reverse wire technique
7. Perform distal balloon inflation and wire deflection technique
8. Put a balloon against the side branch ostium to deflect the wire tip

Advanced Real-time Actions

Reverse side branch wiring technique The wire is shaped to form a hairpin of 3–5 cm from the tip, which itself has a 3–5-mm curve and points in the opposite direction to the hairpin (Figure 5.2a). It is recommended to perform this technique on a soft polymer-coated wire (Fielder FC). The wire is inserted into the guide with the double-folding tip (Figure 5.2b). Once the wire has been advanced beyond the target SB, it is withdrawn to prolapse its tip into the intended SB. Then rotate the wire toward the main lumen clockwise if the tip was pointing toward the left of the patient, and counterclockwise if the tip was pointing toward the right of the patient. When there is enough stiff segment inside the SB (not just the soft tip), the wire will advance further without prolapsing back. By slowly withdrawing and navigating the direction of the tip, the SB is entered (Figure 5.2c). By pulling the wire further with a slight rotation,

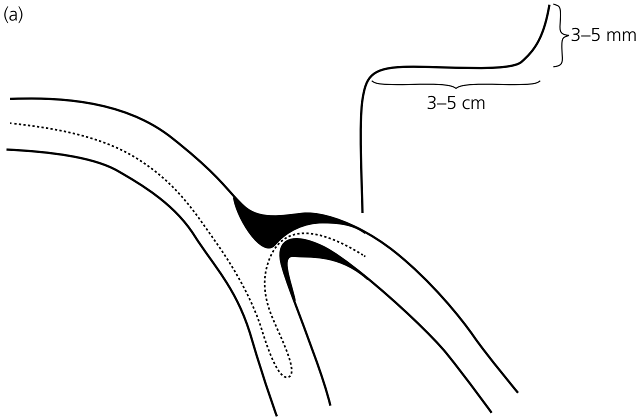


Figure 5.2 (a) The wire is shaped to form a hairpin 3–5 cm from the tip, which itself has a 3–5-mm curve and points in the opposite direction to the hairpin. (b) The wire is inserted inside the guide with its folded short primary and long secondary curves. (c) The wire inserted inside the guide is advanced beyond the target side branch (SB). Then the wire is withdrawn to prolapse the tip into the intended SB. Rotate the wire toward the main lumen: clockwise if the tip was pointing toward the left of the patient and counterclockwise if the tip was pointing toward the right of the patient. When there is enough stiff segment inside the SB (not just the soft tip), the wire will advance further without prolapsing back. By slow withdrawal and navigation of the direction of the tip, the SB is entered. (c) Courtesy of Satoru Sumitsuji MD, FACC.

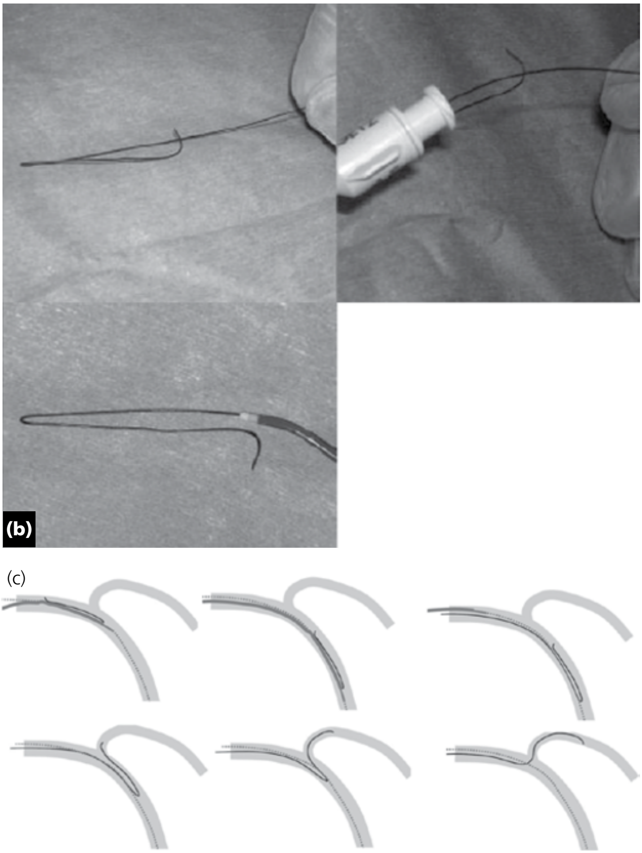


Figure 5.2 (Continued)

it is inserted more deeply. Alternatively, the wire can be inserted in a hairpin configuration into the guide, and after crossing the lesion, the wire is pulled back. However, this is applicable only for very proximal lesions. In distal lesions, the use of a Venture control catheter with double lumen is needed [2, 3].

Tips and Tricks

*****Deflecting the tip of a wire by a distal inflated balloon** Sometimes, it is difficult to curve a wire into an SB with extremely angled takeoff. In a case of a severe ostial lesion of an OM that originated from the LCX at an extreme angle, entry of the OM was unsuccessful because of repeated prolapse of the wire in the main LCX. A small balloon was then advanced to the distal LCX and inflated with its proximal end immediately beyond the ostium of the diseased OM. A new wire was inserted and successfully entered the ostium of the OM, steering it toward the opening of the SB with extremely angled takeoff. In this case, the inflated balloon prevented continuing prolapse of the wire and deflected the tip to the desired retrograde direction [5].

****Crossing a stent cell to access a side branch** In general, all techniques described for difficult SB access can be used, either alone or in combination. If a stent needs to be recrossed, the tip of the wire should be curved well into a wide J, and the whole wire can be advanced while

DEDICATED EQUIPMENT

E

The Venture Control Catheter

The Venture control catheter is a 6-Fr-compatible, flexible, torquable support catheter with a mechanically activated deflectable atraumatic conical tip. A proximal rotating hub allows deflection of the catheter tip over a 90° arc by clockwise rotation. The 8-mm radiopaque tip gives a 2.5-mm bend curve after 90° rotation. The catheter is currently available at 140 cm long with OTW and rapid-exchange versions. The catheter is compatible with all approved 0.014-inch wires. First, pass the wire distal to the intended lesion/branch, then flex the catheter tip to the desired configuration and pull it back against the SB ostium. With exact orientation to the ostium of the SB and firm support, the wire can easily enter the SB despite extremely difficult angulations [4] (Figure 5.3a–d).

Reverse Wire Technique for Wiring a Tortuous SB

The Crusade catheter is a dual lumen microcatheter device that allows the operator to deliver a second wire through the OTW lumen while leaving the first wire in the monorail lumen in place. It is very useful for various scenarios in complex PCI. An outline of the Crusade catheter-facilitated reverse wire technique is as follows. Initially, an approximately 40° reverse sharp curve is made in a polymer-jacket hydrophilic-coated wire at a point about 3 cm from the tip of the wire (Figure 5.4a,b). The wire is inserted into the OTW lumen of the Crusade catheter outside the guide, and the wire is fixed with the Crusade catheter at the point where the reverse bend portion is just distal to the exit port of the OTW lumen of the Crusade catheter (Figure 5.4c). The reverse wire system is then inserted through the hemostatic valve into the guide by softly folding the wire and advanced in the MV to the target bifurcation (Figure 5.4d). After advancing the reverse wire system beyond the bifurcated lesion in the distal MV, the Crusade catheter is pulled back proximally. The wire is then manually steered back into the SB. Some rotational wire manipulation is required in order to direct the tip of the wire into the SB ostium. After selecting the SB ostium with the wire tip, the wire is pulled back carefully as far as the reverse bend portion of the wire situated just at the bifurcation. The Crusade catheter is then removed using the balloon trapping method, and a new flexible microcatheter with favorable crossability is advanced over the wire beyond the sharp curve into the SB. Thereafter, the wire with a sharp curve is exchanged for an ordinary spring coil wire using a microcatheter. PCI is then performed for lesions of both the LAD and diagonal arteries.

Video 5.5 Reverse wire technique.

being rotated. This maneuver will help to avoid inadvertent migration of the tip of the wire under a strut, changing the direction of the whole wire to outside the stent. If there is subtle resistance, wire exit through or behind the struts is suspected. If the stented area has in-stent restenosis and a curved tip fails to cross the stent, then an intermediate wire with a mildly bent tip can be manipulated to cross the stent. Try to have the pictures of the segments in two orthogonal views, so the wire can be advanced inside the lumen as accurately as possible. Additional post-stent inflation with a short balloon at the proximal part of the stent at higher pressure could open cells additionally and dislodge the lateral SB wall, giving room for wire entry. Sometimes these maneuvers are ineffective, and "jailed" wire does not help, especially if the SB is totally occluded. In this situation, an IVUS probe is inserted into the stent and the exact location of the SB is identified. With IVUS in place, a medium-stiffness wire is directed into the SB (the IVUS probe gives additional support to a wire and confirms its true lumen position).

****Advancement of an over-the-wire balloon catheter over a regular-length wire** A regular-length angioplasty wire is inserted and manipulated to cross the lesion. Be sure that the wire tip is positioned at the most distal segment of the artery. An OTW balloon catheter is then advanced over the wire without manual control of the wire. This is performed with

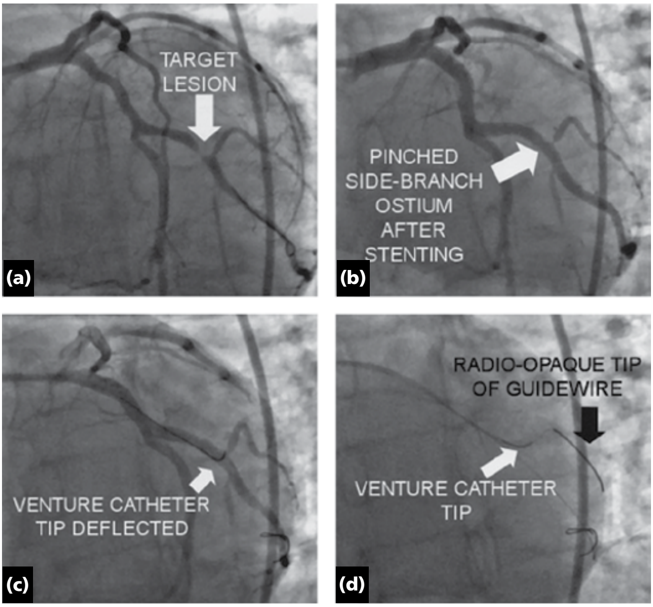

TARGET LESION
(a)
PINCHED SIDE-BRANCH OSTIUM AFTER STENTING
(b)
VENTURE CATHETER TIP DEFLECTED
(c)
RADIO-OPAQUE TIP OF GUIDEWIRE
VENTURE CATHETER TIP
(d)

Figure 5.3 Venture™ control catheter. The catheter gives additional support, keeping the required direction for wire insertion. (a) Perpendicular occurring OM branch. (b) After stenting, the ostium of the OM is severely compromised. (c, d) Directing the wire in the direction of the side branch.

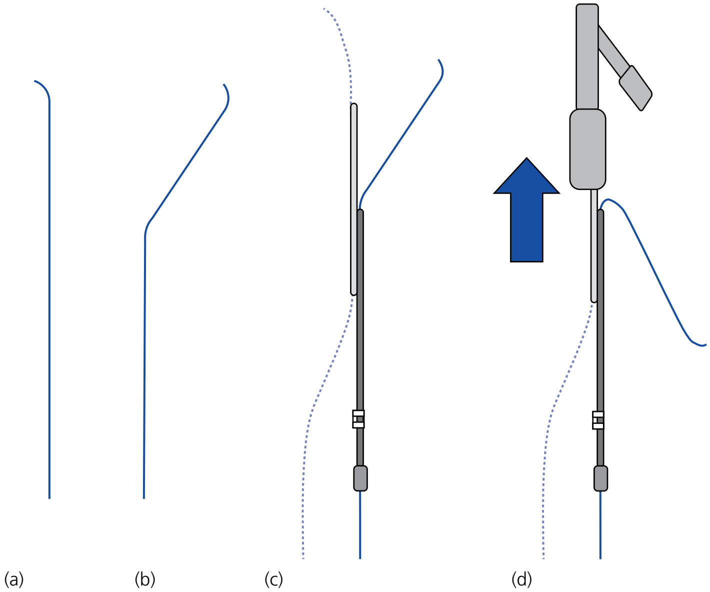


Figure 5.4 How to advance a reverse wire in a double-lumen catheter. (a) Make a curve in the tip as usual. (b) Make a reverse bend of 30°–45° in the floppy part, or a smoother curve with three or four mild bending points. (c) Use a Crusade dual-port microcatheter (Kaneka, Tokyo, Japan) for the main branch wire (already crossed) and insert the reversed wire in the second lumen. (d) Advance the reversed wire system into the Y connector with softly folding reversed wire. The bent point of the reversed wire is positioned at the exit port of the second lumen. Courtesy of Satoru Sumitsuji MD, FACC.

BOX 5.4 TACTICAL MOVE

BEST options in exchanging balloon catheter over a regular-length wire

1. **No Added Cost FIRST Best maneuver**: Use the back end of a regular wire
2. **No Added Cost SECOND Best maneuver**: Inject normal saline through the central lumen during withdrawal of catheter by connecting the balloon to an inflation device (filled with saline) and keeping a constant pressure of 14–15 atm during withdrawal
3. **$ THIRD Best maneuver**: Use an extension wire
4. **Added Cost: an extra balloon**: Use a second balloon to immobilize the wire.

fluoroscopic guidance until the proximal end of the wire reappears through the wire port of the balloon catheter. During the passage of the balloon catheter, extreme care is taken to make the movement as smooth as possible with no tactile evidence of any hindrance. An absolute requirement is to refrain from any forceful forward motion of the balloon catheter over the wire, if any resistance is felt. This precaution would limit any forward migration of the wire. Any resistance or evidence of ventricular ectopy should prompt immediate reassessment of the wire, balloon catheter, and guide positions under fluoroscopy. There is no reported damage to the coronary artery due to inadvertent advancement of the wire. With forward motion of the balloon catheter, increased tension in the wire can back out the guide, so the tip of the guide needs to be watched. This technique is cost-effective as only one wire is used, saving the cost of an extension. It is also advantageous when the proximal end of the wire is damaged and therefore cannot be extended, or if the wire is not constructed to be extended, or no extension wire is available.

****Exchanging a balloon catheter over a regular-length wire** The balloon catheter is pulled back over the wire until the stiff end of this wire remains just within the hub of the balloon catheter. The stiff end of a second wire is then introduced into the catheter hub in an end-to-end apposition to the first wire inside the catheter. This introduction can be facilitated using a 20-gauge intravenous (IV) cannula with the tip placed inside the hub. The balloon catheter is then gradually pulled back over this combination while maintaining a forward push on the second wire. Be sure that this wire is compatible with the lumen size of the balloon catheter.

****Use of a second balloon to immobilize the wire** Insert a second 2.5 × 15 mm balloon and position it 1 cm from the guide tip. When the OTW balloon is withdrawn into the guide distal to the second balloon, this balloon is inflated at 12 atm, anchoring the wire and permitting free removal of the OTW balloon.

The best maneuver ranking of each method for exchanging balloon catheters without sacrificing the wire position across the lesion is listed Box 5.4.

FAILURE TO CROSS A LESION

When a wire does not seem to be able to cross a lesion, the most appropriate step is to check the wire position in a second orthogonal view. The tip of the wire may be in an SB or may have migrated outside the true lumen. Once the wire has been ascertained to be inside the true lumen, other strategies include changing to a stiffer wire, a smaller wire, or a hydrophilic wire, or passing a balloon to near the tip to increase support to the wire.

Confronting the Challenges

Entangled wires with the intravascular ultrasound catheter In complex PCI with advanced physiological or imaging studies by fractional flow reserve (FFR) wire and intravascular ultrasound (IVUS), there is a possibility of entanglement of the wires. In a caseload of 704 patients who had IVUS, 0.5% had entanglement with angioplasty wire, whereas this occurred in 13% with the FFR. The predisposing factor for these entanglements was most likely the short monorail segment of the IVUS catheter. To avoid entanglement of the wires, it is wise to ensure that the short monorail segment of the IVUS seats is near the stiff segment of the FFR wire or angioplasty wire. If entanglement is noticed, attempt to advance the FFR or the angioplasty wire further in order to separate its kinked part from the corresponding tip of the IVUS catheter. Another option is to slide the IVUS catheter distally over the kinked wire. However, over-manipulation may be hazardous and predisposed to generation of loops and further kinking of the FFR. Removal of the complete system as a single unit may be a last resort and a pragmatic option.

Avoiding entangled IVUS catheter and wire When the proximal segment to be crossed is too tortuous and calcified, advancement of the IVUS catheter is less than smooth. If too much force is inadvertently applied to advance the IVUS catheter, displacement of the catheter away from the wire could be induced, and the wire could become kinked. If the problem is not recognized early, advancing a kinked wire can cause perforation or dissection. Because the IVUS catheter slides on a short monorail distal segment, torquing movement is not transmitted well to the tip. This hampers its capacity to negotiate a distal tortuous segment or cross tight curves, lesions, or acute angles.

Tips and Tricks

How to pace with an angioplasty wire? After cannulation of the coronary artery ostium with a guide, a 300-cm, 0.014-inch angioplasty wire is advanced into the distal aspect of the coronary artery. This is connected to an external pulse generator (Medtronic 5348) using an adaptive alligator clip (Medtronic 5833SL). This pulse generator provides a variable output current while maintaining a fixed pulse width. The negative pole (cathode) is attached to the end of the angioplasty wire and the positive pole (anode) to the patient, making the angioplasty wire function as a unipolar lead. Initially, the alligator clip for the anode is attached to the skin using a large skin surface electrode. However, the required current can be unacceptably high using the skin electrode. Therefore, to improve tissue contact, the anode is attached to a steel monofilament suture (3/0 surgical steel monofilament B&S 30) anchored in the subcutaneous tissue near the femoral access site. This steel monofilament suture is routinely used by cardiac surgeons to ground temporary epicardial pacing wires after cardiac surgery and allows lower pacemakers capture thresholds [6].

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CHAPTER 6

Balloon Angioplasty

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

Angioplasty balloons come in various diameters and are crafted from materials like polyethylene and polyethylene terephthalate (PET). These materials allow for precise or oversized diameters, with differing inflation pressures and balloon hardness depending on the material's compliance (compliant or noncompliant).

The balloon catheter can be maneuvered using different systems: an over-the-wire (OTW) system, where the wire runs through the entire catheter shaft; a monorail system, where the wire passes only through the distal segment; or a fixed-wire system, which does not use an indwelling wire. A cutting balloon is equipped with microblades aligned along the sides of the balloon.

When inflated, the mechanism of acute lumen gain varies in calcified lesions, and it involves local and limited dissection, while, in fibrotic lesions, it relies on plaque compression and vessel expansion. Ideally, a balloon has a low profile in its nondeployed state. However, for most lesions, trackability and pushability are more crucial.

Trackability refers to the ease of advancing the balloon over a wire through an angulated coronary artery segment. Pushability is the ability to push the balloon through tortuous segments or across a lesion (Figure 6.1).

BEST PLAYERS

aka Standard of Excellence

The expected result of plain old balloon angioplasty (POBA) or angioplasty with drug-coated-balloon (DCB) is a remodeled lumen with <10% residual stenosis without any dissection and showing laminar flow. The distal flow should be a thrombolysis in myocardial infarction grade 3 flow. If, 5 min after POBA, another angiogram shows no recoil or worsening of flow, the procedure is considered successful.

GAME PLAY

Balloons

The choice of the exact balloon and wire system is less important than the operator's overall approach to the technique of dilation and familiarity with the system chosen, the balloon size, and the capacity to treat possible complications [1]. The balloon:artery ratio should be approximately 1:1. A higher balloon:artery ratio has been shown to be associated with dissection and acute closure.

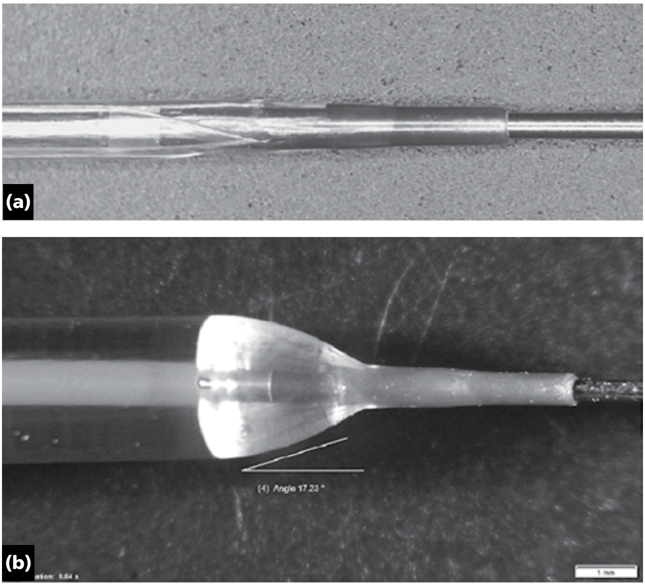

Figure 6.1 (a) Low profile of a balloon. The low-profile tapered tip is for enhanced crossability. The smooth transition between the shaft and the balloon created by laser welding is to ensure flexibility and pushability. In this photo of a Liston™ PTCA balloon, the crossing profile is 0.75 mm (courtesy of USM Healthcare Medical Devices, HCM City, Vietnam, http://usm.com.vn). (b) Evaluation of crossability. When checking the quality of a balloon, the interventional cardiologist would check its crossing profile, lesion entry profile, tip length, and balloon tip taper. As the tip taper is longer, the crossability increases. As the shoulder is shorter, the complication from the edge effect is lower. In this photo of a Liston PTCA Balloon, the crossing profile is 0.75 mm, the lesion entry profile is 0.43 mm or 0.017 inch, the tip length is 2.5 mm, and the balloon tip taper is ~ 17° (courtesy of USM Healthcare Medical Devices, HCM City, Vietnam, http://usm.com.vn).

Discriminating Differences

Compliant balloons Compliant balloons are routinely used due to their low profile (between 0.021 and 0.026 inch, compared to 0.024 and 0.031 inch for noncompliant balloons) and excellent "rewrapping" after deflation. They are particularly beneficial when vessel size is uncertain, such as in an undersized vessel due to chronic low flow or total occlusion. Once the lesion is open and nitroglycerin is administered, the vessel may reveal a larger lumen; a second dilation at higher pressure can further expand a compliant balloon by 20%. Similarly, when targeting multiple lesions in vessels of different sizes, using a compliant balloon can be more cost-effective. Initially, the balloon dilates a lesion in a small-diameter vessel and then moves to a larger vessel where higher-pressure inflation achieves a greater diameter. The compliant balloon is made of polyolefin copolymer. The distinction between compliant and noncompliant balloons is shown in Figure 6.2.

Noncompliant balloons Noncompliant balloons, made from PET, are essential in various situations. For postdilating a stent, a short noncompliant balloon maximizes stent size without overstretching the vessel edges. In long lesions, a noncompliant balloon prevents overstretching the smaller distal segment. In hard and calcified lesions, compliant balloons may overinflate soft segments while failing to break the plaque in hardened areas, leading to temporary enlargement and subsequent recoil. A noncompliant balloon, however, focuses its dilating

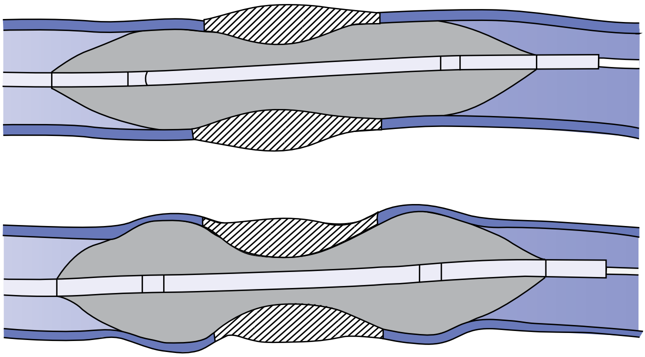

Figure 6.2 Differences between a compliant balloon (upper panel) and a noncompliant balloon (lower panel).

force on the hardened segment without affecting adjacent normal segments. With high pressure, it can fracture the plaque, redistribute the atherosclerotic burden along the longitudinal axis, and create a larger, more stable lumen. Semicompliant balloons are made from polyether block amide, nylon, or polyurethane elastomer.

Marker on balloons A balloon with a marker in the middle should be chosen if the lesion is very tight. When the operator sees the marker in the middle of the lesion, inflation can be started. When doing percutaneous coronary interventions (PCIs) for a long lesion, a balloon with markers at two ends will be needed in order to be sure that the whole length of the lesion is covered.

Long and short balloons Long balloons can distribute inflation pressure evenly across a long lesion with diffuse disease, avoiding multiple inflations or untreated plaques. They lower dissection risk since short balloons may disrupt plaques, allowing blood to enter behind them. Long balloons also maintain vessel curvature during inflation [2]. However, in tapering arteries, they risk underdilating the proximal and overdilating the distal segments.

Over-the-wire and monorail balloons The OTW balloon has a wire inside its core shaft, so its pushability is better. The monorail balloon has only the wire at the distal segment of the shaft, so its pushability is lower. The proximal and mid-segment of the shaft of the monorail balloon is made either of a stainless steel hypotube or of a polyamide or plastic core shaft. The core of the wire shaft is flexible; however, its profile is bigger than that of the hypotube shaft [3].

ADVANCEMENT, POSITIONING, AND INFLATION OF A BALLOON

The left hand of the operator advances the balloon while the right hand or another operator keeps a gentle traction on the wire. The balloon should be advanced by constant pressure rather than by jerky movements. While the balloon is advanced, carefully watch the tip of the guide. As the balloon is being pushed harder, an unstable guide may back out and even become completely disengaged, forfeiting the wire position. If resistance is encountered at the lesion, gentle forward pressure on the balloon catheter, while pulling back on the wire and deeply but gently seating the guide, will often cause the balloon to cross. One way to advance the balloon through a tortuous segment is to advance the wire and guide together.

Failure to Cross a Lesion

When advancing a balloon, if the lesion is too severe, the balloon tip will not cross, and the guide will back out. In this case, the guide should be held steady, engaged more deeply, or replaced. If there is excessive tortuosity of the arterial segment proximal to the lesion, the solutions are (1) to secure a more stable position of the guide; (2) to use a stiffer wire for the balloon to be tracked on; (3) to straighten the artery by asking the patient to take a deep breath; or (4) to use a "buddy" wire, placed adjacent to the primary wire (Figure 6.3). A smaller balloon with a lower profile or length may also succeed in crossing a tight lesion. Once inflated, it creates a channel sufficient for the optimally sized balloon to enter. The best maneuver rankings of each method in advancing a balloon across a tight lesion are listed in Box 6.1.

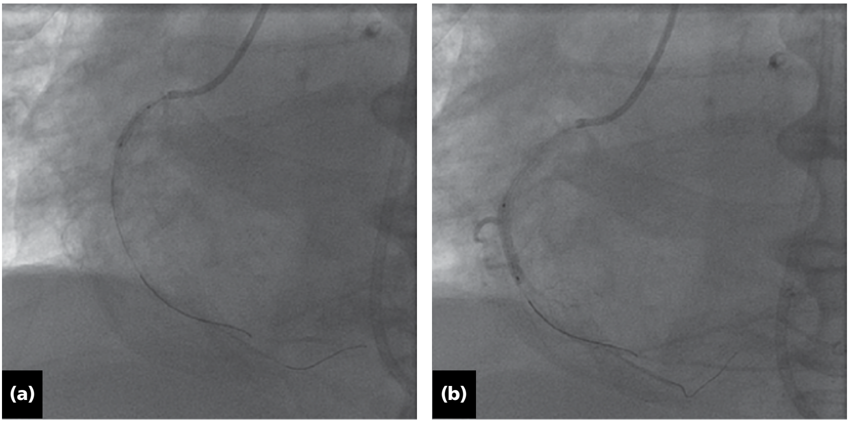

Figure 6.3 (a,b) Buddy wiring.

BOX 6.1 TACTICAL MOVE

Best Maneuver for Advancing a Balloon across a Tight Lesion

1. **No Added Cost FIRST Best Maneuver:** Check the guide position, optimize coaxial alignment, and deep-seat the guide if needed, so the guide can provide sufficient support for advancing the balloon.
2. **No Added Cost SECOND Best Maneuver:** Ask the patient to take a deep breath in order to elongate the heart and the artery (less tortuosity). During this short window of opportunity, advance the balloon.
3. **No Added Cost THIRD Best Maneuver: Paradoxical move** – constant pressure to advance the balloon while pulling the wire so the balloon can cross the lesion. This technique is to decrease the friction between the wire and the lumen of the balloon catheter. It also helps to keep the wire straight and taut so the balloon catheter can slide on it.
4. **$ FOURTH Best Maneuver:** Add a stiffer wire so the balloon can slide on it. The guide will become stiffer and cannot slide back out. The arterial segments are also straightened (less wire bias), and the balloon can be tracked more easily.
5. **$ FIFTH Best maneuver:** Change to a lower-profile balloon (monorail, compliant, with a marker at the center).

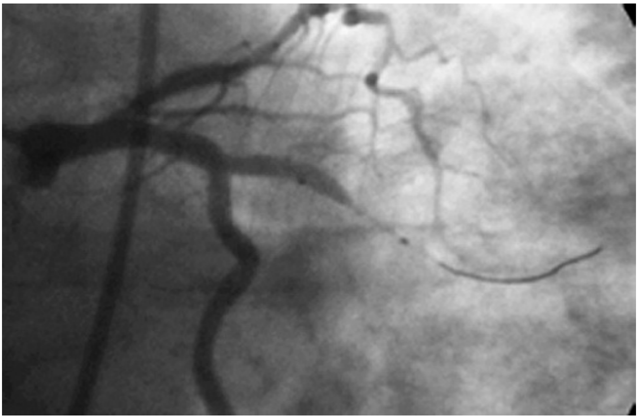

Figure 6.4 There was a tight lesion at the obtuse margin. When the balloon was across the lesion, it obstructed the flow, so a coronary angiogram could not be done to check the exact location of the balloon. Injecting contrast while advancing the balloon will trap the contrast exactly at the center of the lesion. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St Mary Medical Center Hobart, IN, USA.

Tips and Tricks

****Positioning a balloon when the blood flow is cut off** In many cases, advancing a balloon across a severe lesion can obstruct coronary flow. Once the balloon is in position, its exact location cannot be verified before inflation. To ensure proper placement, select a balloon with a length that adequately covers the lesion. Inject the contrast agent while advancing the balloon. The contrast will halt at the center of the lesion. Verify that the balloon's center aligns with the middle of the lesion. Once confirmed, the balloon can be inflated (Figure 6.4).

****Speed of inflation pressure** Most operators inflate the balloon slowly until its waist disappears. This gradual inflation will slowly rearrange the atheromatous material inside the plaque along the longitudinal and radial axes of the artery. In this way, the vessel is being stretched and deformed in a more predictable fashion than with sudden inflations that are more likely to cause extensive tearing (dissection) of the vessel wall.

****Checking the appropriate size of the balloon or stent** After successful inflation of the balloon, 5 s before deflating it, a small injection of contrast will verify the correct fitting of the balloon with the proximal segment of the dilated lesion. If the contrast agent is seen flowing around the proximal segment of the inflated balloon, the balloon is too small for the artery. This is only a rough assessment for the appropriate size of a balloon or stent when intravascular ultrasound (IVUS) is not available (Figure 6.5).

****Looking for collaterals** Collaterals seen during the diagnostic study or appearing with contrast medium during balloon occlusion project a low-risk profile for the patient and reduce the stress for the operator. They can be looked for by injecting contrast while the balloon is about to be inflated. If the contrast caught in the distal vasculature the moment the balloon is fully inflated is washed out promptly, good collaterals are documented. If the contrast stays put, the territory is devoid of collateral blood flow in the event of a later vessel occlusion [4].

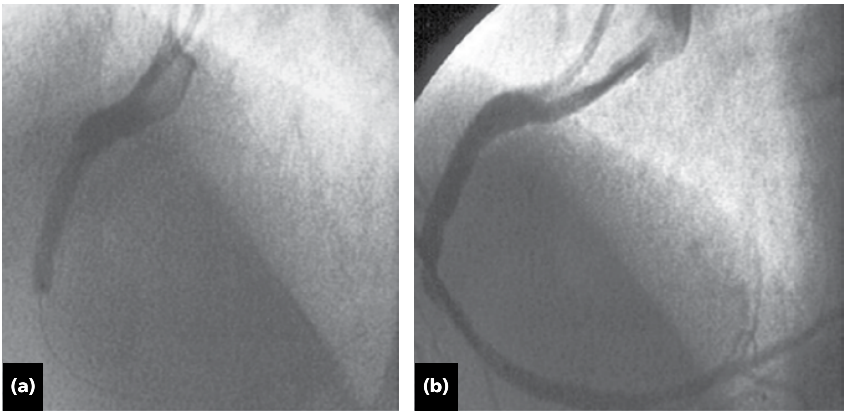

Figure 6.5 Ensuring adequate size of the balloon and stent. (a) A balloon was inflated. Five seconds before deflation, contrast agent was injected. Compare the size of the balloon and the proximal segment. In this case, the size of the balloon is clearly smaller than that of the proximal arterial segment. (b) A larger stent was selected and deployed. A poststenting angiogram showed a larger size of the stented area compared with the proximal arterial segment. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Healthcare System, St Mary Medical Center Hobart, IN, USA.

Real-time Actions

Exchanging an over-the-wire balloon catheter over a regular-length wire It is simple to exchange a balloon catheter over the monorail system. When exchanging a balloon on the OTW system, the indwelling wire must be extended (docked) to a second wire, or a long exchange (300 cm) wire is needed. However, an OTW balloon catheter can be exchanged without the need for another wire. With the indwelling wire held immobile, the balloon catheter is removed slowly until its proximal hub meets the proximal tip of the wire. Attach a 5-mL syringe of contrast to the central lumen of the balloon catheter. Persistently inject the contrast while simultaneously withdrawing the balloon. This persistent injection will move the wire forward while the balloon is removed slowly. To accomplish this exchange successfully, the wire should not be bent, and the catheter should be well flushed before starting the procedure. The Y-Touhy should be open, and the catheter should be positioned in a straight line to minimize friction with the wire [5].

Failure to dilate a lesion A rigid lesion with heavy calcification may prevent the full expansion of a balloon, even if the balloon is inflated to near the rupture pressure. It may be successful, but it exposes the patient to the risk of dissection or balloon rupture. The first option is to use force-focused angioplasty by adding one (or two or three) extra wire(s) besides the inflated balloon. Another option is to exchange a noncompliant balloon so much higher-pressure inflations can be achieved. In lesions with heavy superficial calcium, the problem can be resolved by debulking with rotational atherectomy, or better with intravascular lithotripsy, followed by the use of a drug-eluting stent (DES). The cutting balloon is one of the best options in PCI of the undilatable fibrotic lesion. The best maneuver ranking of each method in dilating undilatable lesions is listed in Box 6.2.

Tips and Tricks

****Force-focused angioplasty** If the balloon fails to break a plaque, it is withdrawn into the guide. A second wire is advanced beyond the lesion. The balloon is readvanced, positioned across the lesion, and inflated as usual. With the wire across the lesion, the pressure is then

BOX 6.2 TACTICAL MOVE

Best Maneuver for Dilating Undilatable Lesions

1. **$ FIRST Best Maneuver:** Add another wire and perform force-focused angioplasty.
2. **$$ SECOND Best Maneuver:** Change to a noncompliant balloon and perform higher-pressure inflation.
3. **$$ THIRD Best Maneuver:** Intravascular lithotripsy for calcified lesion.
4. **$$ FOURTH Best Maneuver:** Rotational atherectomy for calcified lesion.

focused on the wire, which acts as a cutting wire to selectively put pressure on and crack the plaque. Complications include dissection, which can be treated by stenting. Force-focused angioplasty is best done with an undersized noncompliant balloon that allows the operator to go to high pressure without concerns of balloon oversize relative to vessel size or balloon rupture.

****Balloon for calcified lesion** If rotational atherectomy is unnecessary, an intermediate-size noncompliant balloon (2.0 cm × 10 mm) is preferable. A balloon that is too short may easily slide out of the lesion, while a longer one can be challenging to navigate through the calcified segment. An intermediate-size balloon strikes the right balance. Inflating the balloon at maximal pressure (25–28 atm) allows for effective lesion dilation without overdilating or dissecting the artery.

****Balloon angioplasty of large vessels** The current maximum balloon size is 4 mm in diameter, so when the coronary artery or the saphenous vein graft is larger than 4 mm, the hugging balloon technique or the use of a peripheral balloon is suggested. The two balloons are positioned side by side and inflated simultaneously. The combined diameter will be 70% of the sum of each balloon alone, and the cross-section area would be oval rather than round [6, 7].

NEW DISRUPTIVE TECHNOLOGY

Intravascular Lithotripsy

Intravascular lithotripsy is discussed in Chapter 20.

Failure to Deflate the Balloon

Inability to deflate the balloon is a rare occurrence. Possible causes are excessive twisting (more than 360° to cross a distal lesion) or entrapment in the distal portion by a tight lesion. The best maneuver ranking of each method in case of a balloon that does not deflate is listed in Box 6.3.

Tips and Tricks

*****How to puncture an undeflatable balloon?** After exhausting all maneuvers without success, a rarely used approach involves advancing a small new OTW balloon directly next to the proximal end of the entrapped, still inflated balloon. Remove the 0.018-inch wire from the OTW balloon and reinsert it with the stiff end facing forward. Inflate the new balloon at low pressure, positioning the sharp end of the wire at the center of the vessel lumen. Attempt to puncture the trapped, inflated balloon.

While there is a risk of coronary perforation, the puncture hole should be small and unlikely to result in significant complications. Moreover, vessel trauma from balloon rupture can be much more extensive and unpredictable than a single pinhole puncture [8].

BOX 6.3 TACTICAL MOVE

Best Options When the Balloon Fails to Deflate

1. **No Added Cost FIRST Best Maneuver:** Deflate the balloon with the inflation device.
2. **No Added Cost SECOND Best Maneuver:** Deflate the balloon with a 50-mL syringe connected directly at the inflation port.
3. **No Added Cost THIRD Best Maneuver** Dilute the contrast material in the deflator with saline, resulting in a decrease in the viscosity of fluid within the balloon. The negative pressure that was generated across the kinked balloon might be adequate to deflate the balloon.
4. As a **last resort** Inflate the balloon to rupture it. Prepare for damage control from dissection or coronary perforation.
5. Puncture the balloon with the back end of a wire.
6. **$$** Surgical removal of the balloon.

Confronting the Challenges

Impending rupture due to material fatigue Besides rupture due to excessive inflation or calcified plaque, another cause of rupture is material fatigue [9]. Balloon fatigue generally occurs after numerous inflations and deflations of a reused balloon, rarely seen now. The sign of material distress or fatigue is that there is a focal bulging in the balloon during inflation. It is suggested that, even when faced with an unyielding stenosis, inflation pressure above the rupture level marked by the manufacturer should be avoided.

Entrapment of deflated balloon during withdrawal Even though the incidence of entrapment of a deflated balloon is low, when it happens, it is quite traumatic to the patient, operator, and interventional team. The entrapment can happen in any unpredicted way. Different options for freeing an entrapped balloon are listed in Box 6.4. There are no practical best options if based on a hypothetical scenario. Different modalities of treatment can be selected on a trial-and-error basis.

BOX 6.4 TACTICAL MOVE

Best Options for Freeing an Entrapped Balloon

1. **No Added Cost FIRST Best maneuver:** Push the balloon forward, then pull it back.
2. **No Added Cost SECOND Best maneuver:** Twist the balloon in an attempt to rewrap the balloon before pulling back.
3. **$** Insert a stiffer wire alongside the entrapped balloon before pulling the balloon back so that the artery is straighter.
4. **$$** Advance a second wire distally, then insert an OTW balloon alongside the entrapped balloon and inflate the new balloon at low pressure to free the entrapped balloon.
5. **$$** If the OTW balloon cannot be advanced, advance a balloon on a wire alongside the entrapped balloon and inflate the OTW to free the entrapped balloon.
6. **$$** Advance a commercial microsnare and tighten the loop as near to the balloon as possible, then pull the balloon back.

Tips and Tricks

*****Using a commercial snare to remove a trapped balloon** Cut the proximal end of the balloon catheter. Advance the snare using the balloon catheter as a wire. On arriving at the entrapped balloon site, loop the snare around the balloon and tighten the loop by advancing the transport catheter. Pull the snare and the catheter together to free the balloon [10]. Be prepared to unwrap the snare and pull it back alone if it is not possible to remove the trapped balloon.

*****Repeated balloon rupture** Balloon rupture can repeatedly happen in a patient with in-stent restenosis. Usually, a ridge of calcium protrudes into the lumen and punctures the balloon. Management of this problem includes the use of a stronger balloon or rotational atherectomy, which can be problematic because it can ablate the metallic stent struts. Another novel method to prevent recurrent balloon rupture during dilation of calcified conduits is to leave the ruptured balloon in place while a second balloon catheter is used to perform further angioplasty. This technique relies on the material of the deflated, injured balloon forming a barrier over the sharp edges of the calcified conduit, thus protecting the second balloon from rupture [11].

*****Damage control for balloon rupture** Balloon rupture is seen under the fluoroscope as a quick dispersal of contrast agent from the balloon, with short contrast opacification of the vessel or decrease in the inflation pressure. When this occurs, slowly withdraw the balloon proximally to the lesion and inject some contrast to detect if there is a perforation. The balloon is then removed if not entrapped in the lesion. Stenting should be performed if there is dissection.

CUTTING BALLOON

Because of the presence of the microblades at its side, the cutting balloon is quite stiff and is difficult to curve around sharp bends. To overcome this problem, the cutting balloon is designed with a very short length.

Real-time Actions

While dilating the cutting balloon, a slow inflation strategy is used. There should be a 3–5-s interval between each atmosphere increase to ensure that the peripheral balloon wings unfold slowly first around the blades before inflation of the central core of the balloon. Rapid inflation could result in puncturing a hole in the balloon by the blades. The manufacturer's guidelines for balloon inflation should be adhered to: 1 atm inflation every 5 s for a maximum of 6–8 atm. Some operators also recommend deflation of the balloon at the same gradual rate. Finally, withdrawal of the cutting balloon should not be attempted until an adequate time interval has elapsed to allow full rewrapping of the balloon.

Confronting the Challenges

Extraction of stent by cutting balloon The cutting balloon features blades mounted along its length. During inflation, the blades protrude outward and become exposed. Upon deflation, a mechanism wraps the balloon back with multiple wings. During this rewrapping process, there is a risk of creating an anchor formed by the balloon and the blades, or simply because the balloon, reinforced by the blades, is of higher profile. This can cause the balloon to become stuck in the stent struts, preventing its withdrawal. If the cutting balloon is pulled forcefully enough, it may also pull the stent or parts of the stent with it. Since the artery lumen has had its stent removed, this could result in avulsion and acute occlusion [12, 13].

BOX 6.5 TACTICAL MOVE

Best Maneuver for Freeing an Entrapped Cutting Blade

1. **No Added Cost Push/Pull:** An avulsed longitudinal atherotome may be trapped between the stent strut and the vessel wall. The entrapped cutting balloon should first be advanced forward and rotated either clockwise or counterclockwise in order to unhook the protruding microtome.
2. **$$ Buddy Balloon:** If the atherectomy has become deformed in its mid-portion and has snagged a stent strut, a second balloon can be introduced alongside the entrapped cutting balloon and inflated in order to change the conformation of the cutting balloon and release the stent strut. Although the "buddy balloon" technique may be useful in changing the configuration of the entrapped cutting balloon, the risk of balloon rupture from a protruding microtome is highly likely.
3. **$ Guide "Sheath":** With the extreme longitudinal arterial force sometimes required to remove an entrapped cutting balloon, the proximal vessel can sustain a traction injury, resulting in proximal coronary dissection. With some 6-Fr guides, the guide can be deep-seated within the coronary artery, and the retraction force can be applied at the orifice of the guide. If the cutting balloon has been dilated through a stent strut, this maneuver is unlikely to be successful but will lessen the degree of traction injury to the vessel.
4. **$$ Snare:** If a large (>8 Fr) guide has been used (or a smaller guide can be exchanged for a larger one), the hub of the cutting balloon can be cut, and a snare can be placed over the shaft of the cutting balloon and its wire. The snare can then be advanced through the guide to the cutting balloon, allowing for greater traction force to be directly applied to the entrapped device.
5. **$$$ CABG:** If the entrapped cutting balloon cannot be retracted despite these maneuvers, or if anterograde flow cannot be sustained, surgical consultation for CABG and removal of the entrapped cutting balloon should be undertaken. Although this therapy is a last resort, it is required in some cases with refractory cutting balloon entrapment [15].

Cutting balloon entrapment can occur due to several factors, such as the unintended passage of the coronary wire through a stent cell, followed by the cutting balloon, which can lock the microblades in the stent struts. This may lead to the avulsion of the struts upon attempted withdrawal or be associated with fracture of the microblades.

****Freeing an entrapped cutting blade** If difficulty is encountered advancing the cutting balloon, the preliminary presumption is that there is a possibility of wire passage through stent struts. Excessive resistance to the advancement of the balloon should be interpreted as an indication of this, and rewiring should be done. Where doubt exists, IVUS can be used to confirm that the wire is within the stent lumen throughout its course. The best maneuver ranking of each method in removing an entrapped cutting balloon is listed in Box 6.5 [14].

CORONARY INTERVENTION FOR CANCER PATIENTS

Cancer patients are predisposed to coronary events due to a persistent proinflammatory and prothrombotic state. Acute coronary syndrome (ACS) in this population may arise from tumor embolism, severe coronary vasospasm, or Takotsubo cardiomyopathy. These patients are at increased risk for both bleeding and thrombosis. In those with a favorable cancer prognosis and reasonable life expectancy, revascularization – either PCI with only POBA (so no prolonged anti-platelet treatment is needed) or coronary artery bypass grafting (CABG) – should be considered when symptoms persist despite optimal medical therapy and control of precipitating factors.

Tips and Tricks

Management of thrombocytopenia In cancer patients with thrombocytopenia, the risks of both bleeding and thrombosis are elevated. Notably, low platelet counts do not confer protection against ischemic events; instead, they are paradoxically associated with increased thrombotic risk. There is no absolute platelet threshold below which coronary angiography is contraindicated. A platelet count of 20 000–30 000/μL is generally sufficient to proceed with PCI in the absence of additional coagulation abnormalities. Surgical revascularization may be feasible when platelet counts exceed 50 000/μL. Thromboelastography may be helpful in assessing bleeding risk, particularly the likelihood of intracranial hemorrhage, in patients with platelet counts below 30 000/μL prior to PCI.

Antithrombotic strategy In patients undergoing PCI with platelet counts below 50 000/μL, an initial lower dose of unfractionated heparin (30–50 U/kg) is recommended, and glycoprotein IIb/IIIa inhibitors should be avoided. For platelet counts above 50 000/μL, standard-dose heparin (50–70 U/kg) or bivalirudin may be used. An activated clotting time (ACT) of 250 seconds can typically be achieved even with reduced heparin dosing.

Antiplatelet therapy Aspirin should generally be continued in thrombocytopenic patients with ACS, as withholding it is associated with worse outcomes. It can be administered safely in patients with platelet counts above 10 000/μL. Dual antiplatelet therapy (DAPT) can be used in patients with platelet counts between 30 000 and 50 000/μL. Recommended DAPT durations are as follows: 2 weeks following plain balloon angioplasty, 4 weeks for BMS, and 6 months for second- or third-generation DES. Ticagrelor and prasugrel should be avoided in patients with platelet counts below 50 000/μL. Triple antithrombotic therapy should not be used in this population.

Device selection For patients with platelet counts below 30 000/μL, balloon angioplasty alone may be appropriate, especially when urgent non-cardiac surgery or intervention is required. For platelet counts above 30 000/μL, bare-metal stents (BMS) may be considered if non-cardiac procedures can be delayed for at least 4 weeks. Newer-generation DES may be used when platelet counts exceed 30 000/μL and no immediate surgical or chemotherapeutic intervention is planned.

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CHAPTER 7

Stenting

Nguyen Thuong Nghia, Mihas Kodenchery, Thach N. Nguyen, and Marco Zuin

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⧖, <10 min extra; ⧖⧖, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Just as a clinical cardiologist must be familiar with the pharmacological properties of a new cardiovascular drug or the mechanism of a new therapeutic device, interventional cardiologists must understand the fundamental physical and bioengineering principles of stenting. This knowledge ensures that the most appropriate stent can be selected, positioned, and deployed for a given lesion.

Easy Delivery: High Longitudinal Flexibility, Low Profile

An undeployed stent mounted on a delivery balloon should be able to easily navigate the tortuous segments proximal to the target site without injuring the intima or causing spasm. This smooth delivery is referred to as "high trackability," as it indicates that a stent with excellent longitudinal flexibility can be passed easily over a wire. The two key properties – high longitudinal flexibility and low profile – allow the stent to reach the target site within the desired time frame and with minimal manipulation (Figure 7.1a–c). A stent can easily cross an angulated segment if its length fits within the widest interval of the curve. If the stent is longer, it can be advanced as long as it is able to bend or curve, and the arterial segment is not too calcified to relax and accommodate the stent compliantly.

Perfect Deployment = Great Radial Strength and Curve Conformity

Once deployed, a stent must have sufficient radial strength to resist the elastic recoil of the media and the shifting plaque. In emergency situations, it must be strong enough to seal a dissection entry, patch a dissecting flap, or brace against the persistent compression of a

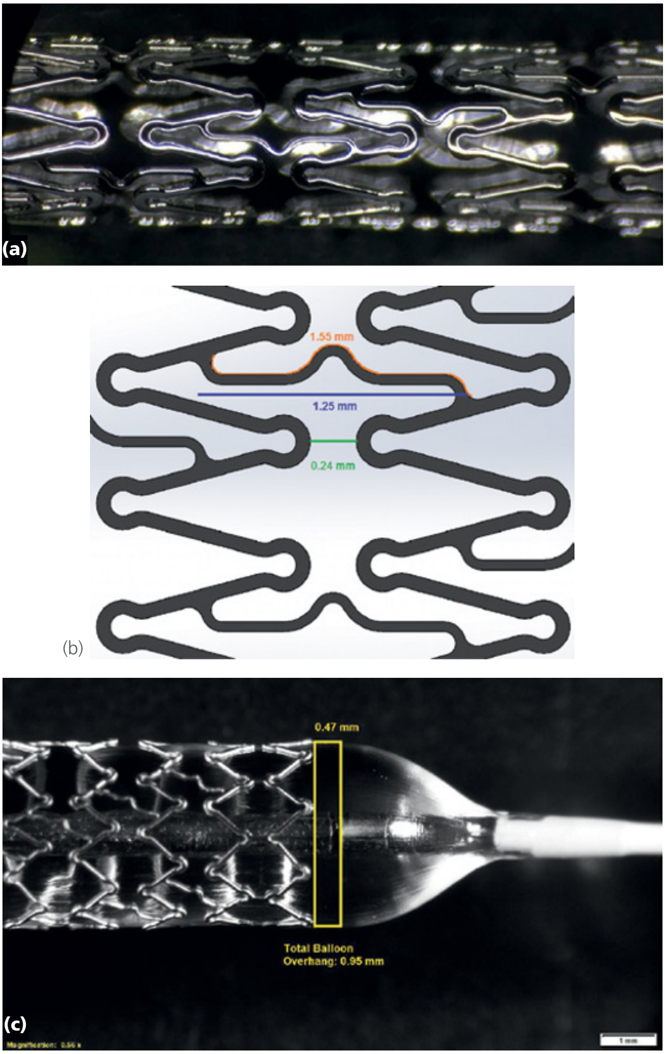

Figure 7.1 (a) Design for low profile and flexibility. In general, a stent is designed as a series of adjacent crowns or rings that are formed by horizontal struts folded in a zigzag fashion like an accordion. These rings or crowns are connected to each other by the longitudinal struts or connectors. Photo of a semideployed VSTENT Sirolimus Eluting Coronary Stent System, courtesy of the USM Healthcare Factory JSC, HCM City, Vietnam: http://usm.com.vn. (b) Horizontal and longitudinal strut design for flexibility. As a stent is composed of a series of adjacent crowns or rings, the length of these rings is short and interrupted. They are connected by longitudinal struts that are thin and short. In this example of a VSTENT, the thickness of the struts is 65 μm, while the length of each ring is 1.30 mm and the length of each connecting or longitudinal strut is 1.25 mm (or 1.55 mm if including the middle curve). These short and interrupted struts folded along the length of the stent maximize its flexibility. Currently, the current benchmark for the thickness of the struts ranges between 65 μm (VSTENT) or 91 μm (Endeavor stent) and 151 μm for a bioreabsorbable vascular platform. Photo of the semideployed crowns or rings of the VSTENT Sirolimus Eluting Coronary Stent System, Source: Courtesy of The USM Healthcare Factory JSC, HCM City, Vietnam, http://usm.com.vn. (c) Balloon overhang is the length of the balloon extending outside the proximal and distal ends of the stent. This is important because it is equated to the amount of trauma inflicted on healthy tissue adjacent to the stent and the degree of late peri-stent restenosis. There is a need for a smooth transition between the balloon and the stent in order to facilitate the advancement of the stent, while the stent needs to stick well on the balloon without being embolized. Photo of an undeployed VSTENT Sirolimus Eluting Coronary Stent System. Source: Courtesy of The USM Healthcare Factory JSC, HCM City, Vietnam, http://usm.com.vn.

growing intramural hematoma. In nonemergency situations, an expanded stent should maintain its frame against the systolic compression of a myocardial bridge.

Additionally, an adaptively deployed stent should conform to the shape of a curved segment rather than straightening it while still providing a large, desired lumen. These two properties, excellent radial strength and curve conformity, contribute to an ideal angiographic result. After deployment, the struts should be well embedded in the arterial wall, preventing systolic contraction or diastolic relaxation. This ensures the stented segment is immobilized, preventing further injury to the intima, which serves as the nidus for endothelial thrombotic formation. Optimal apposition of the struts to the vessel wall also ensures effective drug delivery from a drug-eluting stent, reducing intimal hyperplasia and preventing in-stent restenosis.

PRACTICAL CLINICAL EVALUATION OF A STENT

Is This Stent Flexible?

In general, if a stent has no stiff longitudinal shaft along its length, it will be flexible (Figure 7.2). With better supportive equipment to advance a stent (stiffer wire, more stable guide), or in the case of minimal tortuosity, the flexibility of a stent is not a major concern in today's busy cardiac catheterization laboratories. However, most patients undergoing percutaneous coronary interventions (PCIs) are older and have more complex lesions – more tortuous, more calcified, located in a distal position – so flexibility is still a major concern in the selection, advancement, and deployment of a stent in the elderly patient group.

What Is the Radial Strength?

Most currently available stents possess adequate radial strength. However, the key concern is the even and reliable distribution of their struts. High radial strength is particularly important in lesions of the left main trunk, at the anastomotic site of a saphenous vein graft (SVG), or in elderly patients, where the lesions are composed of extensive fibrotic tissue and have

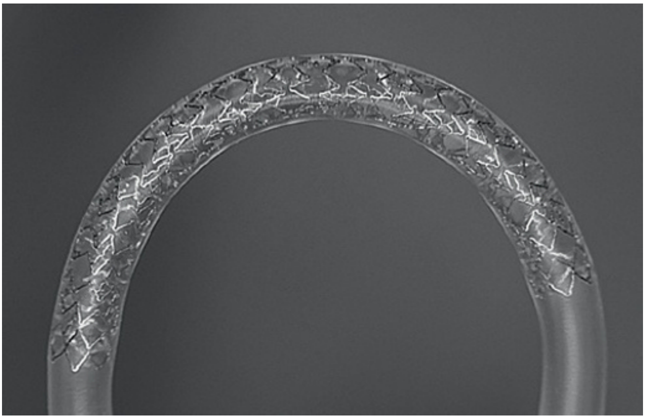

Figure 7.2 A flexible stent can curve itself in order to navigate a tortuous arterial segment. When a stent is bent, the cells in the middle expand to a greater extent than the cells at both ends. In this example of a VSTENT, the design is to have open cells in the middle and closed cells at both distal segments. This design of mixed closed and open cells increases the radial strength at both ends while preventing the diametric difference (dog-boning effect) between the delivery balloon at recommended inflation pressure and the stent at both ends. In this VSTENT, the diameter difference is a minuscule 0.141 mm, thus reducing vessel injury at the stent ends after expansion. Photo of the VSTENT Sirolimus Eluting Coronary Stent System. Source: Courtesy of USM Healthcare Factory JSC, HCM City, Vietnam: http://usm.com.vn.

significant recoil pressure. It is also crucial for long-term success in stenting of the carotid, femoral, popliteal, or tibial arteries, which may be exposed to external compression.

Does this Stent Brace Itself Against the Wall with a Strong Strut Network?

Intravascular ultrasound (IVUS) has demonstrated that stenting a lesion shifts the mass of atheromatous material along the longitudinal and radial axes. To achieve the best luminal diameter, a just-deployed stent must provide a strong network of struts to fence off the recoiling atheromatous mass and provide controlled shifting of the plaque burden along the longitudinal axis. It must be able to prevent any intraluminal herniation of the plaque through its struts and any possible distal embolization of the material from the plaque.

Is the Stent of Open or Closed Cell Design?

In general, if the adjacent crowns or rings are connected at every internal inflection point, the design is classified as closed cell. If some inflection points are free of connecting struts, the design is classified as open cell (Figure 7.3). As there are fewer connecting struts, the open-cell design stent is more flexible. However, as open-cell stents curve better along the tortuous segments of the arterial wall, the cells in the middle expand more widely than the cells at both ends.

Cell Size or Cell Design: Which One Is More Important?

A stent with an open-cell design offers better flexibility and conformability. However, the larger diameter of these open cells (e.g. 1000 μm) at the concave surface after stent deployment can predispose to more plaque prolapse, debris embolization, and fish scaling. Fish scaling occurs during maximal deployment when the acute angles of the folded horizontal struts protrude like fish scales, potentially perforating the intima or adventitia. A large cell diameter is also beneficial in bifurcation lesions, where optimal results require the absence of obstructing struts across the ostium of the side branch.

In practice, stents with an open-cell design and low cell surface area should provide acceptable flexibility and excellent scaffolding, helping to prevent plaque prolapse, debris embolization, and fish scaling. They are particularly suited for calcified lesions with less tortuous arterial segments

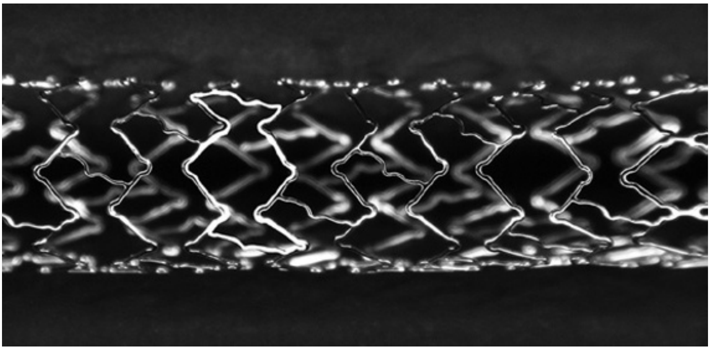

Figure 7.3 After deployment of a VSTENT, the size of the open cells in the middle of the stent is approximately 3.40 mm^2 whereas that of the distal closed cells is 1.7 mm^2. These engineering characteristics are very important because the strength of the struts is greater at both ends in order to fence off the recoiling effect of the arterial wall and provide a controlled shifting of the plaque burden along the longitudinal axis. The wide surface area at the middle of the stent is important for opening to the side branch in bifurcation stenting without an obstructing strut across the ostium. Photo of the VSTENT Sirolimus Eluting Coronary Stent System. Source: Courtesy of USM Healthcare Factory JSC, HCM City, Vietnam: http://usm.com.vn.

proximal to the lesion. If advancing the stent is not problematic, a closed-cell design may be more appropriate. For lesions at a bend, stents with an open-cell design may not offer adequate scaffolding but provide better conformability. Recently, helically designed stents have shown excellent flexibility and kink resistance, with uniform cell size at flexion points and no scaling.

Is the Stent User Friendly?

In general, an elective stenting procedure should take no more than 30 minutes if the equipment is reliable and user-friendly. Each step of the procedure should be completed on the first attempt. In addition to strong guide support, the success of stent delivery depends on the size and flexibility of the stent–balloon complex, the compliance of the arterial segments proximal to the target site, and the adequate dilation of the lesion site.

A flexible, small stent can easily slide over a floppy wire, while a stiffer wire is needed to track a bulkier, stiffer stent. Short stents can typically navigate sharp bends, but some longer stents may not. During delivery, the stent should remain securely attached to the balloon to avoid the risk of inadvertent embolization. If delivery fails and an undeployed stent is being withdrawn into the guide, there should be no resistance felt.

The stent should align in a straight line with the tip or distal end of the guide, without forming a sharp angle between the tip of the guide and the proximal end of the stent. This ensures the stent does not slip off the balloon. If such slippage occurs, the guide, stent, and wire should be withdrawn together as a single unit.

Ultimately, the choice of stent depends on the operator's preference, experience with specific designs, and a careful assessment of the stent's structural features to maximize both technical and clinical outcomes.

ADVANCING A STENT

GAME PLAN

A stent is a long stainless steel tube with its wall laser cut in a lace pattern that dictates the flexibility and radial strength. The forward movement of a stent depends on the interplay between its length and stiffness and the flexibility of the arterial wall. A short stent can go anywhere. A long stent may not be able to be advanced through a short calcified arterial segment because the arterial wall does not accommodate the length of the stent. However, a long stent can curve easily across a noncalcified arterial segment. Box 7.1 shows the different scenarios in which a stent can cross a curved segment.

BOX 7.1 SCENARIOS IN WHICH A STENT CAN CROSS A CURVED SEGMENT

1. Short stent and mild curve.
2. Long stent and accommodating arterial wall (expanding to the push of the stent).
3. Intermediate and long stent and nonconforming calcified arterial wall: stent not moving forward.

When a stent fails to move forward, it is imperative to assess the stability of the guide position, the stiffness of the wire, the tortuosity and calcification of the vessel, and the flexibility and length of the stent.

Guide The tip of the guide should be coaxial with the ostium of the coronary artery, and advancement of the device should not back out the guide. If it does, the guide is not stable enough and should be deep-seated. If the guide is deeply seated and does not back out but the stent does not advance, then the change of guide shape may not necessarily prove helpful. For a guide to be more stable, it needs to have a large contact area on the opposite aortic wall. For a guide to be stiffer, it has to be of a larger size or be encased in a long (70 cm) sheath.

Wire If the guide position is stable and the artery is tortuous and calcified, then an extra support (as stiff as or stiffer than the first) wire may sufficiently compensate for this mildly deficient guide backup and the nonaccommodating proximal arterial segment. The mechanisms of success of this extra wire are that it makes the guide stiffer (with an extra wire inside the guide), straightens the arterial segment proximal to the lesion (so the stent can slide more easily), and hopefully decreases wire bias at the curve by projecting the wire away from the inner curve and positioning it more at the center of the lumen. However, if the guide is very unstable (e.g. a Judkins left for PCI of the left circumflex artery [LCX] in a patient with a long main artery [LM]), an extra wire may not be sufficient to correct the problem.

Artery If the artery is moderately or severely calcified and tortuous, and the issue is not related to an unstable guide or an insufficiently stiff wire, it may be due to a stiff, nonconforming arterial segment. One possible cause is that the proximal segment of the LCX is encased within the atrioventricular groove, making it less accommodating even in the absence of calcification. Is there a lesion in the proximal segment obstructing stent advancement? If so, dilation of the proximal segment, followed by stenting, is necessary.

Often, the issue involves a hard, eccentric, calcified plaque, with the friction from the rough surface of the plaque creating significant resistance, preventing the stent from passing. An additional extra support wire may not be strong enough to guide the stent away from the plaque. In such cases, a slippery hydrophilic wire could facilitate stent passage. Alternatively, plaque modification with rotational atherectomy could effectively resolve this issue.

Stent The most important features are the stent's flexibility and the smoothness of the stent surface over the balloon. Stents that have minimal flare-up of the stent struts upon bending (fish scaling) typically perform best in such cases. Longer stents have a tendency to "lock" over bends, particularly if flaring up of the stent struts occurs while the stent bends. This "locking" can be released by gentle motion and steady, gentle force on the stent. Sometimes pulling the wire slightly can lead to the release of the lock. Shorter stents generally behave more favorably in tortuous vessels [1].

Tips and Tricks

****Testing the road** After the lesion has been predilated with a balloon, a stent is prepared to be advanced. If the proximal segment is tortuous, the question is whether the stent can succeed in arriving at the lesion site. One way to test the possibility is to advance the deflated balloon with its wings still out. If the balloon can recross the tortuous segment and lesion, there is a greater chance (>50%) that a stent can also recross.

****The "buddy wire(s)" technique** The "buddy wire" approach requires one extra support or heavy duty wire to straighten the artery. As the stent cannot be advanced through a first wire, advance a second, stiffer wire across the lesion, then advance the stent as usual. Once the stent has been positioned across the lesion, it is deployed [2]. The buddy wire can be removed before or after stent deployment (jailed wire). If one extra wire does not work, try to slide the stent on the hydrophilic wire. An additional third wire may help.

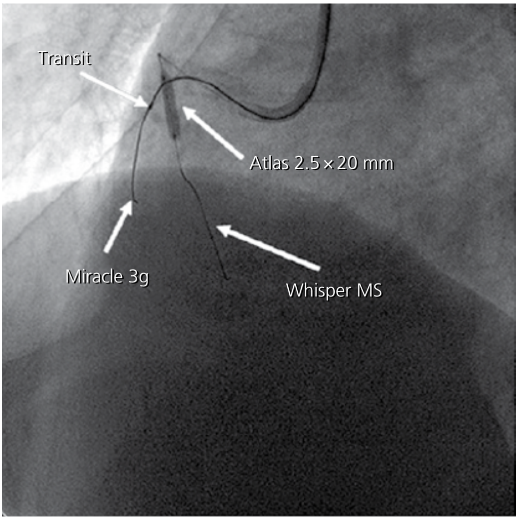

Figure 7.4 During intervention of a chronic total occlusion of a right coronary artery, in order to keep the guide stable, a wire was inserted into the conus branch and a small balloon was inflated to prevent the guide from backing out. Source: Courtesy of Dr. Faisal Latif, University of Oklahoma, OK, USA.

*****The proximal anchor balloon technique** The wire and balloon are advanced into a nontarget vessel, with the balloon inflated to nominal pressure to stabilize the guide (Figure 7.4).

*****The distal buddy balloon technique** After many failed attempts, an over-the-wire balloon is advanced beyond the target lesion. There the balloon is inflated to entrap the wire. While pulling the entrapped wire to keep tension on it, the stent is advanced successfully on this taut wire. The balloon is removed before deploying the stent; if not, the balloon will be "jailed." The mechanisms for the success of this technique are explained in Box 7.2 [3]. The negative sides to this trick are (1) the need for an extra balloon; (2) inflation of a distal balloon can cause endothelial denudation, which starts the restenosis process; (3) rupture of a new plaque causing thrombosis or acute occlusion; and (4) the balloon will get stuck if it is not withdrawn before stent deployment.

*****The proximal deflecting balloon technique** A small balloon is advanced near the questionable area, occupying the eccentric dead end space just proximal to the lesion. It provides enough strength to guide the second balloon or stent smoothly over the lesion surface. This technique can also be useful in other scenarios, such as when it is difficult to pass a balloon catheter into a stent for postdeployment high-pressure dilation or when a retrieval or aspiration catheter is difficult to pass through a stent at the end of the procedure, especially after using distal protection devices.

BOX 7.2 MECHANISMS OF THE DISTAL BUDDY BALLOON TECHNIQUE

1. Pulling on the wire will seat the guide more deeply and firmly.
2. Trapped by the balloon, the first wire can be pulled and become a stiff rail over which the stent is easily tracked.
3. Straightening the proximal segment of the vessel causes less (or more) wire bias.

BOX 7.3 TACTICAL MOVE

BEST Maneuvers When a Stent Fails to Advance

1. **No Added Cost FIRST Best maneuver:** Secure a more stable guide position or, if possible, the guide can be deep-seated safely.
2. **No Added Cost SECOND Best maneuver:** Constant forward pressure on the stent catheter while pulling the wire back to decrease friction inside the stent catheter lumen and to straighten the stent catheter while asking the patient to take a deep breath in order to elongate and straighten the artery.
3. **$⌛ THIRD Best maneuver:** Advance a second, stiffer wire to straighten the artery (the buddy wire technique). Advance the stent on the second, stiffer buddy wire; occasionally, stents may actually advance more easily over a softer wire.
4. **$$**⌛⌛💧 Dilate the proximal segment or remove plaque to facilitate stent advancement.
5. **$**⌛ Change to a larger guide or one with a different curve to achieve better backup and less friction at the ostium.

BOX 7.4 OTHER EXOTIC MANIPULATIONS CAN BE DONE WITHOUT GUARANTEED SUCCESS

1. Change the stent to a shorter one if the problem is tortuosity of the proximal segment.
2. Select a different type of stent with better flexibility.
3. Bend the stent to conform it to the curve of the artery.
4. The buddy balloon technique: advance a second balloon beyond the deployment area and inflate the balloon to hold the first wire.

In a case report, wire bias caused by mildly calcified plaque, even after using a second buddy wire, led to the distal edge of the stent becoming caught on the plaque, preventing further advancement. Gentle inflation of the buddy balloon to 2 atm created a platform, allowing the stent to be deflected from the plaque and advance to the desired position. However, this technique has limitations. A larger guide is required, and the vessel size must be sufficient to accommodate two balloon catheters. Additionally, manipulating multiple wires and balloon catheters can potentially induce trauma to the proximal parts of the vessel [4].

As there are many options to overcome the difficulty of stent delivery, which one is best for the situation? This decision requires critical thinking so the procedure can be finished on time, without wasting equipment. The list of preferential best options is shown in Boxes 7.3 and 7.4.

DEPLOYING A STENT

As more PCIs are done without formal surgical backup, many lesions are strategically underpredilated to be stented immediately at standard size and higher pressure. Other operators suggest direct stenting without prior balloon inflation.

Direct Stenting

Direct stenting is a feasible and safe technique when used for selected coronary lesions that lack significant calcifications and/or angulation. The degree of stenosis is generally not a limiting factor, particularly in cases of unstable angina where thrombus plays a key role. For type A

BOX 7.5 FACTORS FAVORING SUCCESSFUL DIRECT STENTING

1. No calcium at the target and other coronary vessels.
2. No severe proximal tortuosity.

lesions, accurately measuring the reference diameter to size the stent is straightforward. However, in lesions with chronic distal vasoconstriction due to low flow, the angiographic distal reference diameter may appear smaller.

Sometimes, the strategy of direct stenting can backfire, particularly due to the potential for incomplete stent deployment (e.g. caused by lesion fibrosis, calcification, or balloon rupture), stent loss, and difficulty retrieving the stent. Additionally, inaccurate stent placement may occur if there is poor distal vessel opacification. Therefore, it is crucial to assess for the presence of significant calcium in the lesion and the proximal segment prior to angioplasty and stenting, considering rotational debulking or intravascular lithotripsy if necessary. Fluoroscopy alone is not sensitive enough to detect superficial calcium.

A moderate push should be used when attempting to pass the stent to the desired position at the lesion site. Prolonged or forceful manipulation should be avoided, as it can cause the stent to be stripped from the balloon and embolized distally. The factors favoring successful direct stenting are outlined in Box 7.5 [5].

Predilating Balloon Angioplasty

The goal of predilation is not to achieve a perfect result but to facilitate proper stent positioning. Overly aggressive angioplasty can eliminate key angiographic landmarks of the lesion, making the location for stent deployment uncertain and potentially leaving incomplete coverage of the injured segment. However, if the lesion is not heavily calcified or fibrotic, and predilation is insufficient, the balloon may not fully dilate during stent deployment. This could result in a partially deployed stent, which can serve as a nidus for future subacute thrombosis.

Tips and Tricks

****Deployment of a stent in a tortuous artery** When a stent is deployed in a very tortuous arterial segment, the vessel wall forms many invaginations beyond the struts rather than being well stretched. To maximize the length of the stented segment along the natural curve of the tortuous artery and to ensure that the struts are well apposed to the vessel wall, the stent is deployed while the patient takes a deep breath. Deep inspiration makes the heart more vertical and elongates the artery, and in that short window of opportunity, the stent is deployed.

****Appropriate sizing for tapering artery** After successful inflation of the balloon, 5 seconds before deflating it, a small injection of contrast agent will verify the correct size of the balloon with the proximal segment of the dilated lesion. The same maneuver after deploying a stent will verify the correct size of the stent with the proximal segment of the dilated area. If contrast agent is seen flowing around the proximal segment of the inflated stent–balloon complex, the stent needs to be inflated with larger-sized balloons. If the stent is underdilated, the now-deflated balloon is pulled back a few millimeters to avoid overdilating the distal end and is inflated again with higher pressure to achieve greater size. This is only a rough assessment of the appropriate size of the balloon or stent when IVUS is not available.

ADVANCED AND EXOTIC TECHNIQUE

Deploying a Stent without an Angiogram

In a case report of stenting the mid-left anterior descending (LAD) artery beyond the left internal mammary artery (LIMA) insertion, balloon angioplasty and stenting had to be done through the native artery using anatomic landmarks (e.g. ribs, clips, side, etc.). The reason for this was that no contrast injection could be done through the native LAD, while the flow through the LIMA was too brisk for visualization. Severe tortuosity in the LIMA prevented the passage of bulky interventional devices. In such a case, balloon inflation and stent deployment can be done through anatomic landmarks without an angiogram [6].

When prior diagnostic angiogram studies are available, they may serve to direct placement of wires without additional contrast administration. Intravascular imaging devices may then provide all necessary anatomic information to complete revascularization goals. Additional coronary wires in branches near target lesions may provide additional anatomic guidance. Slow and patient manipulation of coronary wires is essential to avoid inadvertent intimal injury. However, the prolonged time requirements of this approach and lack of intermittent contrast injections increase the risks of intracatheter thrombus formation, as demonstrated in this case. Periodic catheter flushes with saline and use of adjunctive medications to control thrombosis may reduce this risk. A contrast-free approach may not be possible or advisable in highly complex lesions, ostial lesions, LM lesions, chronic total occlusions, or other circumstances in which frequent lesion visualization might be necessary.

This approach may increase certain other risks, including failure to identify a distal coronary perforation related to wires (not discernible with IVUS or other intravascular imaging devices). For this reason, wires with aggressive tip characteristics should be used with caution. Small dissections and intracoronary thrombus may be poorly identified by IVUS. While intracoronary optical coherent tomography (OCT) provides superior resolution of these features, optimal OCT imaging requires contrast administration [7].

Tips and Tricks

*****How to opacify the LIMA with high flow** Use a guide with a tip large enough to cause flow standstill. Inject contrast while advancing the guide. As the contrast moves forward and opacifies the distal diseased segment, the tip of the guide occludes the ostium of the LIMA and slows the coronary flow enough that the distal segment can be seen.

*****Poststent deployment balloon inflation** After stent deployment, the postdilation high-pressure balloon should be short and noncompliant. The balloon must be short enough to fit entirely within the length of the stent without causing any tears at either edge. If the balloon is longer than the stent, the portion exceeding the stent's length should be positioned at the proximal end. This positioning helps avoid the need to recross the stent if a rupture-induced dissection occurs at the proximal end rather than the distal end. It also prevents over-dilation of the adjacent distal segment, which is often smaller than the proximal reference segment. Furthermore, placing the excess balloon length proximally reduces the risk of balloon entrapment or tethering at the distal end of the stent, which could make balloon retrieval difficult or even impossible.

Assessment of the Result of Stenting by OCT

Stent malapposition is identified by a visible separation between at least one stent strut and the vessel wall in IVUS images. In OCT images, it is defined as a distance between the center of the strut's reflection and the vessel wall greater than the actual stent thickness plus 20 μm

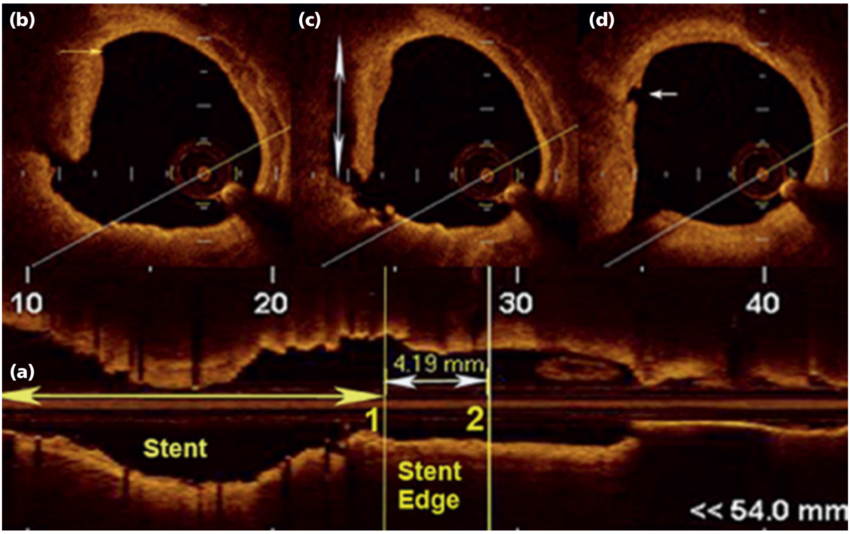

Figure 7.5 OCT images of proximal stent edge dissection. (a) Longitudinal view. The longer double arrow indicates the stented region, and the shorter double arrow indicates the edge dissection. Lines 1 and 2 show the longitudinal extent of the dissection (4.19 mm in length). (b) Image corresponding to line 1 in the longitudinal view. The double arrow shows the thickest part of the dissection flap where measurement was performed (0.51 mm thick). (c) Image showing the frame with the greatest length of dissection flap (vertical double arrow), where measurement was performed (1.65 mm in length). (d) Image corresponding to line 2 in the longitudinal view. The arrow shows a cavity in the vessel wall that represents the end of the stent edge dissection [9]. Schematic illustration of the measurements of the dissection flap thickness and length, on cross-sectional image view. The horizontal double arrow shows the thickest part of the dissection flap, where measurement was performed. The vertical double arrow shows the length of the dissection flap. Measurement was performed in the cross-sectional image with the longest flap. (a–d) Source: Reproduced with permission from [9] / HMP Communications, LLC.

(the resolution limit of OCT). Stent edge dissection is characterized by the disruption of the luminal vessel surface at the edge segments (Figure 7.5). Event-free survival was significantly lower in patients with edge dissection and a flap thickness greater than 0.31 mm compared to those with a thinner flap or no dissection [8].

Tissue prolapse is defined as the protrusion of tissue between stent struts, extending inside a circular arc that connects adjacent struts, as seen in both IVUS and OCT images. Thrombus is characterized as an irregular, low-echoic mass, often mobile, protruding into the vessel lumen and sometimes becoming detached from the vessel wall, as identified by IVUS. On OCT images, intracoronary thrombus is defined as a mass extending beyond the stent strut into the lumen, with significant attenuation behind the mass (Figure 7.6) [9].

RECROSSING A STENTED AREA

Often, during PCI near a previously stented area, there is a risk that any interventional hardware (balloon, rotablation, cutting balloon, IVUS, directional coronary atherectomy, AngioJet™ catheters (Cook Inc., Bloomington, IN, USA), etc. [11]) may dislodge or remove the stent. The first event in a later chain of catastrophes is that a wire exits through stent struts. Inability to pass balloons, stents, etc. over the wire must therefore be taken seriously as a clue to this possibility of wire wrong exit. The wire should be advanced with a wide J curve or repositioned,

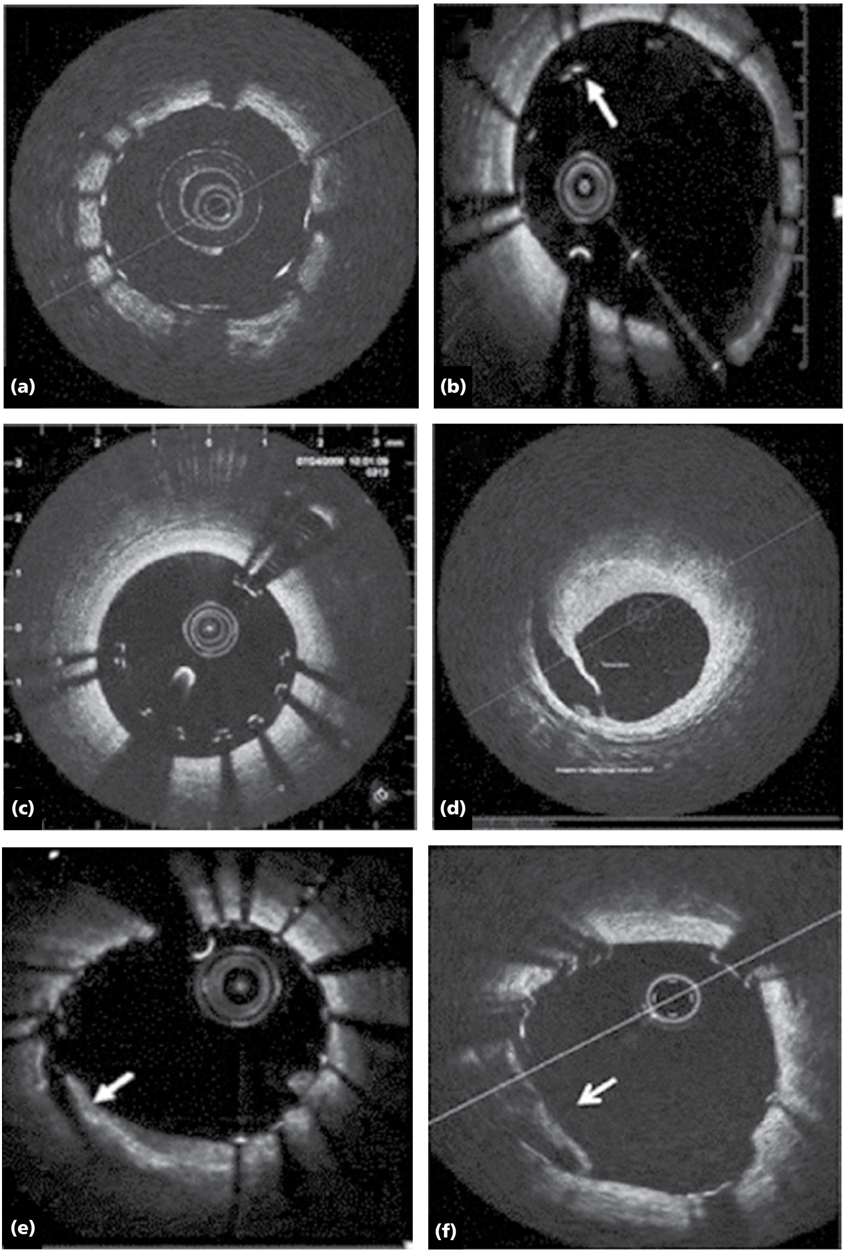

Figure 7.6 (a–c) Incomplete stent apposition; (d) edge dissection; (e) intrastent dissection; (f) tissue prolapse. Source: Reproduced with permission from [10] / John Wiley & Sons.

avoiding the previously stented area. Angiographic views can be deceiving and misleading. Sometimes there is no resistance when the wire exits through the struts [8]. Some caveats for PCI near a previously stented area are listed in Box 7.6.

BOX 7.6 REVIEW OF ANGIOGRAM DURING PCI NEAR A PREVIOUSLY DEPLOYED STENT

1. Review prior angiogram for stent position and type.
2. Advance the wire easily with its tip in a wide J curve. The tip should move freely.
3. Resistance to crossing the device suggests passage between or behind struts (sometimes there is no tactile feeling of resistance by a hydrophilic wire even if it goes through a side strut).
4. Use two orthogonal views in order to assess access, avoiding damage to ostial stents by diagnostic catheter or guide.
5. IVUS of parent vessel only. Avoid deeply inserting the IVUS catheter through struts.

Tips and Tricks

****Dottering the stented area** Hold the interventional device (stent, balloon, cutting balloon, IVUS catheter, etc.) and advance it by gently dottering. By moving the device forward and backward in a gentle motion, the indwelling wire will also be bounced gently in the same manner. Since the tip of the wire cannot move further, the forward energy is converted into an up-and-down motion, causing the wire to bounce along the full diameter of the lumen. This helps center the wire and creates an opportunity for the interventional device to enter the newly stented area. However, this technique may not work if the wire cannot bounce up and down due to a small vessel diameter, if the wire is tightly encased, or if the monorail segment of the device (e.g. the IVUS catheter) is too short to transmit the dottering motion (Box 7.7).

BOX 7.7 UNFAVORABLE FACTORS REQUIRING THE DOTTERING TECHNIQUE

1. Suboptimal opening of stent.
2. Wire encased in a tight area.
3. Small vessel diameter.
4. Too short monorail segment of the balloon or IVUS catheter.

****Steer the wire to a new branch** Steer the wire in a different direction or to a different branch to lessen wire bias and increase more wire centering; hopefully, it will help to advance the stent.

*****Other exotic techniques** When crossing a stented segment of a vessel, a short stent can pass more easily than a longer one. If the stent fails to cross a stented segment while being tracked on a soft wire, a stiffer wire with less wire bias can direct the balloon–stent complex more to the center of the stented segment and help the stent to cross. If the stent fails to pass with a stiff wire in place, changing to a softer one may help. If a balloon cannot cross a stent, the balloon-on-a-wire type has a higher chance of crossing the stent because there is no "step up" from the wire to the balloon and therefore no "lip" on the balloon's nose to get caught inside a stent strut. Unfortunately, these balloons cannot be inflated at high pressure to fully dilate a stent [9]. A new wire with a stiffer distal tip that is flexible in its radial axis (the wiggle wire) can move up and down the tip of the stent–balloon complex as it is advanced. Recrossing a stented area that was deployed a long time before can be easier, probably due to endothelial coverage of the struts and any small gaps between them.

*****First balloon deflecting second balloon away from problematic area** In a case report, it was suggested to position a balloon at the site of resistance where the balloon could not enter the stented area. Inflate the balloon at 2 atm. Then advance a second balloon as the working balloon. The first balloon will deflect the second balloon away from the problematic area and allow the second balloon to enter the stented segment [12].

****Recrossing a stent with a bent stiff wire** There are often situations where a balloon needs to be advanced across a stent for high-pressure postdilation, to perform angioplasty in the distal area, to patch a distal edge dissection, or to stent the distal segment. If a balloon fails to recross a stent, it is usually because the tip of the balloon has engaged the stented arterial segment eccentrically or nonaxially. To facilitate coaxial entry of the balloon within the deployed stent, a stiff wire can be shaped so that a bend in the wire directs the balloon tip into the center of the stented lumen, thereby aiding its passage.

****Recrossing a stent with a movable tip wire** The Steer-It™ wire (Cordis Corporation, Johnson & Johnson company, Miami, FL, USA) is a 0.014-inch diameter wire consisting of a thin filament affixed at its distal tip to that of a hypotube in which it is housed. A sliding component of the proximal handle allows the operator to variably deflect the curvature of the distal end in vivo. After exiting the guide, the curvature at the tip is put in minimally. Then, at the proximal edge of the stent, the curvature is maximized to >90°, and the wire is advanced through the stent. The knuckle formed while crossing the stent prevents passage behind the struts. Thereafter, the tip is relaxed again to suit the tortuosity of the distal vasculature [13] (Box 7.8).

BOX 7.8 TACTICAL MOVE

Best Maneuvers for Recrossing of a Stent

1. **No Added Cost FIRST Best Technique:** The technique is to gently bounce the device forward and backward; because these movements are limited, the wire will bounce up and down (more wire centering) and create the chance to enter the lumen.
2. **No Added Cost SECOND Best Technique:** Steer the wire in a different direction, or to a different branch or side branch, in order to lessen wire bias and increase wire centering; hopefully, it will help to advance the stent.
3. **No Added Cost THIRD Best Technique:** Engage the guide in a more stable position or deep-seat the guide to change the entry direction of the wire and hopefully lessen wire bias.
4. **$⌛ FOURTH Best technique:** Insert a second, stiffer wire to straighten the vessel.

Other exotic techniques can be tried; however, the chance of success is lower and not guaranteed.

1. Change the current wire to a stiffer one.
2. Use a shorter balloon or stent.
3. Rotate the balloon catheter while advancing it, and let the catheter enter the stent by itself through its rotational energy (like torquing the Judkins right catheter to engage the right coronary artery ostium).
4. Bend the wire and place the bent segment near the ostium of the stent to be crossed in order to position the wire more at the center of the entrance of the stented segment and to decrease wire bias.
5. Use a newly designed wire that wiggles its long tip up and down along the radial axis so the balloon–stent complex enters the lumen at the center (wiggle wire).
6. Use a more flexible balloon or stent.
7. Use a fixed-wire balloon to cross the stent.
8. Use a fixed-wire balloon to track alongside a buddy wire.
9. Mount a stent on a balloon with the tip partially inflated.

(*Continued*)

10. Park a balloon at the resistance site, and advance the second balloon as the working balloon. The first balloon would deflect the second balloon away from the problematic area.
11. If only the balloon needs to enter the stented segment, inflate the balloon with 1–2 atm so the balloon will center the wire at the lumen and facilitate the crossing of the wire and balloon.

REDEPLOYING A STENT

With the trend of primary stenting or lower-pressure balloon predilation, on many occasions, a stent cannot be fully expanded due to an unexpectedly severely calcified vessel wall. In other cases, a stent can be crushed by inadvertent insertion of the dilation balloon through a strut. How to redeploy the stent?

Tips and Tricks

****How to cross a crushed stent** After failure to advance a wire through the main lumen of a crushed stent (Figure 7.7a,b), the next step would be to take another picture from another orthogonal angle (90°opposite to the first angle) in order to locate the exact position of the possible opening (Figure 7.7c). Then a balloon with a marker in the middle of the balloon is advanced. As soon as the marker is seen in the middle of the lesion, it is certain that the lesion has been crossed (Figure 7.7d). From there the stent is redilated successfully (Figure 7.7e).

Deploying a Stent after Failed Expansion by a Balloon

In order to redeploy a stent, usually the operator would insert and inflate a noncompliant, high-pressure balloon. Even so, on occasion, very high-pressure balloon inflation fails to expand the stent. Then conventional laser angioplasty in a blood medium would provoke local dissection behind the stent struts. The theory is that excimer laser irradiation of blood results in vapor bubble formation and acousto-mechanical trauma to the vessel wall, causing localized dissection. Usually, during regular laser angioplasty, intracoronary infusion of normal saline is required to displace the blood and minimize the blood irradiation and consequent arterial wall damage. In case of failure to expand a stent due to unexpected heavy calcification, excimer laser irradiation would provoke local dissection, weaken the vessel wall, and allow full expansion of the stent [14].

Rotablation through an unexpanded stent could be done in an exceptional case. However, what is the mechanism of enlarging the stent by rotational atherectomy? After rotablation, the angiogram showed an optimal result with a linear coronary dissection. IVUS showed optimal expansion by ablating away some of the struts. The main concern is that the burr could get stuck in the stent and require surgery for its removal [15] (Box 7.9).

Confronting the Challenges

Rotational atherectomy after stenting Rotational ablation to freshly implanted stents has been demonstrated to be safe in side branch access through the struts of the stents in the radial (more or less perpendicular) direction. In in-stent restenotic lesions, longitudinal rotablation may be considered safe as the stents are “protected” or “scarred down” by the surrounding intimal hyperplasia.

Advantages and limitations There are several concerns associated with longitudinal rotablation of a freshly placed stent. First, compared to accessing stent-jailed side branches, more metal needs to be ablated to relieve the circumferential restriction of an underexpanded stent.

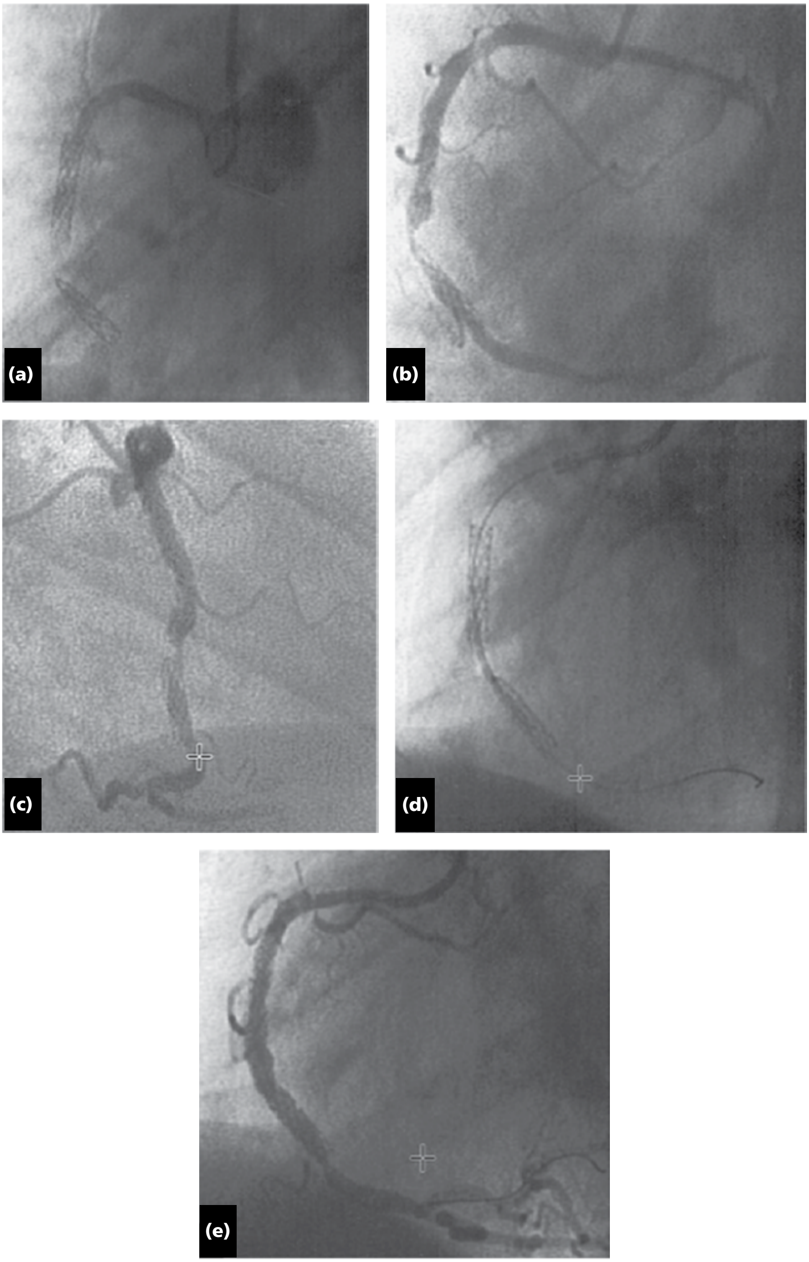

Figure 7.7 (a) The second stent is crushed at its opening. (b) The right coronary artery in the left anterior oblique view. (c) Because the wire was unable to enter the stent ostium, another angiogram was done in the right anterior oblique view (90°opposite) in order to ascertain the exact location of the true opening. (d) A balloon with a marker in the middle was advanced across the stent. (e) The stent was redilated successfully. Source: Courtesy of the Cardiac Catheterization Laboratories of Community Heathcare System, St Mary Medical Center, Hobart, IN, USA.

BOX 7.9 TACTICAL MOVE

BEST Maneuver for Redeploying a Stent after Prior Expansion Failure

1. **No Added Cost FIRST Best maneuver:** Use the same balloon and increase inflation pressure to maximum. Be sure the proximal end is well inflated. Inflate the balloon with the maximum possible high pressure so at least the proximal end is opened as much as possible in order to facilitate the reinsertion of a new balloon. It is not always easy to reinsert a new balloon inside an underdeployed stent.
2. **$⌛ SECOND Best maneuver:** Change the current balloon to a high-pressure, noncompliant balloon.
3. **$$⌛⌛💧💧**: Laser angioplasty in a blood medium to cause local dissection behind the stent struts, then reinflate the balloon to redeploy the stent.
4. **$$⌛⌛💧💧💧**: Rotablation (for experienced operators).

Additionally, the spatial orientation of the stent in relation to the rotational direction of the burr raises concerns about burr entrapment and unwanted movement of the stent. While particle size is known to influence rotation deceleration in plaque atherectomy, little is understood about the metallic debris generated from rotablating a stent. In an in vitro model of rotational atherectomy in side branches jailed by stents, the released stent fragments ranged from 1.7 to 17 mm in size, depending on the stent type. Compared to plaque atherectomy debris (mostly <5 μm), some of the metallic debris (10–30 μm) may be too large to be cleared through distal circulation. Therefore, strict adherence to standard rotational atherectomy techniques is essential when rotablating a stent. These techniques include high-speed, low-deceleration, and short burr durations; gentle forward burr advancement; and the use of platelet glycoprotein IIb/IIIa inhibitors and Rotaglide® (Boston Scientific, Maple Grove, MN, USA).

In rotablating a metallic stent, when the burr ceases to advance, rather than continuing to push harder, a new burr with sharp cutting edges should be substituted for more effective penetration. There should be no need to alter the size of the burr, the speed of rotation, or any other technical factor [16].

*****Redeploying an embolized stent** In case of inadvertent embolization of an undeployed or partially deployed stent, the best way to resolve the problem is to ensure that the wire is stable inside the main lumen and to reinsert the same balloon and reinflate it (especially the proximal half, so any further attempt to insert a new balloon will be facilitated). To insert a new noncompliant balloon into the stent is not easy. If it is successful, deploy the stent with prolonged higher pressure. However, it is difficult and/or will take a lot of time, patience, skill, and luck to advance a new balloon across a partially deployed stent. If this is not successful, the stent must be removed.

Be careful when moving the balloon because the stent is stuck to (not all the time) the lesion and can easily be dislodged if the distal end is small and the proximal end is large, such as at the insertion site of an SVG. It is easier to dislodge a stent in a retrograde fashion with a large, winged, and bulky, poorly rewrapped inflated balloon.

*****Management of balloon rupture** Balloon rupture can occur after stent deployment, especially with used balloons. IVUS has shown that jagged calcified lesions can penetrate the stent lumen, causing repeated balloon perforation. A case report indicated that while a PET balloon ruptured twice, a nylon balloon withstood high pressure without puncture [17]. Early detection of heavy calcification could have benefited from rotablation atherectomy, but once the lesion is stented, ablation with the burr is not ideal due to the stent's proximity to calcified plaque [18].

*****Stent deployment after balloon rupture** When a balloon ruptures during stent deployment, withdrawal of a partially inflated balloon can dislodge the stent into the proximal segment. To deploy the stent, some experienced senior operators suggest (1) keeping the ruptured balloon in place, (2) using a 20-mL syringe filled with contrast, and (3) injecting 2–3 mL very quickly to inflate the balloon in order to deploy the stent. Keelan et al. were able to partly deploy the stent using an automatic power injector. Using 50% diluted contrast at a rate of 20 mL/s over 0.25 s and a pressure limit of 200–400 psi, they found that 1 mL was injected before the pressure maximum was exceeded. The stent was sufficiently deployed with the damaged balloon to allow the removal of the balloon [19]. Many times, the balloon ruptures because of a tiny pinhole, so these quick injections can sufficiently inflate a balloon and partially deploy a stent; however, these injections can cause a jet injury at the arterial wall and may cause perforation.

COVERED STENT

Two polytetrafluoroethylene (PTFE)-covered stents are available on the market: the JoStent coronary graft (JoMed International, Sweden), in lengths of 9–26 mm and a maximum achievable diameter of 5.0 mm, and the Symbiot covered stent system (Boston Scientific Corporation, Natick, MA), 20–45 mm in length and a maximum of 5.0 mm in diameter. The JoStent has been constructed by a sandwich technique: an expandable PTFE membrane, 50 μm thick, has been placed between two JoStent Flex stents made of 316 L steel. The Symbiot stent is a self-expanding nitinol stent encased in a thin, porous, expanded PTFE membrane. The JoStent GraftMaster can be delivered through a 6-Fr (inner diameter 0.068 inch) guide, while the Symbiot stent requires an 8-Fr (inner diameter 0.086 inch) guide [20].

Tips and Tricks

****Hand-crimp a covered stent** If the stent must be hand-crimped, most of the hand-crimping should be applied to the middle of the stent and not to the ends to make sure the balloon material is not damaged. Always inflate the balloon first before mounting the stent, because the winged balloon material tends to hold the crimped stent in position more reliably than an uninflated balloon [21].

*****How to check the integrity of a hand-crimped balloon before deployment** To avoid crimping a stent on a ruptured balloon, three observations to confirm the integrity of the balloon should be checked prior to advancement. In the case of a hand-crimped stent, the balloon–stent complex can be checked again when the stent is at the tip of the guide, before engaging the coronary artery, so there is still time to retrieve it if needed [22].

CASE REPORT

Exclusion of Coronary Aneurysm with Covered Stent

The usual approach to exclude a coronary aneurysm is a technique that involves deployment of a covered stent to be anchored from the distal to the proximal nonaneurysmal segments of the artery.

In this specific case, the length of the segment to be covered with a stent was approximately 32.6 mm as measured by quantitative coronary angiography. Additionally, it might have been difficult to advance a long PTFE-covered stent through the steep bend

(*Continued*)

in the proximal right coronary artery (RCA). Therefore, sequential deployment of shorter stents was a reasonable choice. Stent deployment in the proximal part of the RCA first could straighten the sharp bend and make distal stenting easier. Therefore, implantation of the stents from proximal to distal was attempted. A 2.5–5.0 × 26 mm JoStent Coronary Stent Graft was mounted and hand-crimped onto a 4.0 × 30 mm Maverick™ balloon catheter. The JoStent stent graft was positioned in the proximal portion of the RCA to cover the proximal part of the entry site of the aneurysm. The aneurysm was partially excluded from the coronary lumen. To make passage of the second stent easier, the JoStent stent graft in the proximal RCA was postdilated with a 4.5 × 20 mm Bypass Speedy balloon catheter to 14 atm. A 3.5 × 19 mm premounted JoStent stent graft was positioned in the mid-segment, partially overlapping the proximal JoStent stent graft, and deployed at 18 atm. Postdilation of the overlapping segment between the two JoStent stent grafts was performed with a 4.5 × 20 mm Bypass Speedy balloon catheter inflated to 12 atm [23].

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CHAPTER 8

Transradial Approach

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

In the last decade, the scope of modern interventional cardiology has dramatically changed with new user-friendly devices and more complex interventions performed in high-risk patients. The default transfemoral approach (TFA) is burdened with relatively frequent access site bleeds (depending on definition) and rarer but potentially serious complications as retroperitoneal hematoma (RPH), arteriovenous fistula (AVF), and pseudoaneurysm (PA). The impact of access site complications may include increased morbidity, mortality, need for surgery, blood transfusions resulting in longer hospital stay, higher costs, and worsened quality of life [1]. The recent advent of closure devices has led to faster hemostasis and ambulation, but they appear to have similar overall complication rates as compared to manual compression [2]. Greater safety, lower costs, and early return to prior level of activities are desirable not just from the patient's perspective but also from the standpoint of healthcare economics and efficiency. The transradial approach (TRA) achieves excellent procedural success rate, virtually eliminates access site complications, allowing rapid ambulation, and even facilitates safe performance of PCI in an outpatient setting with same-day discharge [3]. This is due to the superficial location of the radial artery (RA), the extensive palmar collaterals, lack of adjacent veins or nerves, and hence easy and safe hemostasis, no ischemic sequelae, or injury of surrounding structures.

Patient Selection

Patient selection for transradial coronary angiography and intervention (TRI) is accomplished by checking the pulse as well as by Barbeau's test, which confirms patent collateral flow. Barbeau's test is a combination of plethysmography and pulse oximetry used to evaluate the collateral circulation. In patients undergoing a second procedure via the same radial site, a reverse Barbeaus test (referred to as a reverse Allen's test when assessment of the plethysmographic waveform is excluded in favor of simple visual assessment of palmar blush) should be performed to assess for patency of the RA. In this situation, the operator releases pressure over the RA rather than the ulnar. This may detect a proximal RA occlusion that is asymptomatic, thus potentially excluding this access site for a repeat procedure [4].

Contraindications

The rare contraindications include severe bilateral Raynaud phenomenon and no radial pulse. Additionally, except in rare instances, TRI should be avoided in the presence of an ipsilateral arteriovenous dialysis fistula.

ARTERIAL ACCESS

Real-time Actions

Radial artery puncture Equipment and patient preparation is simple and similar to that for femoral approach. The hand is positioned along the body with the palm pointing upward and obliquely. After local skin anesthesia with 0.5 ml 1% lidocaine, puncture is performed with 21–19 G venous cannula or bare needle. Optimal puncture site and relevant anatomic structures are shown in Figure 8.1. The puncture technique using an angiocath IV and needle angulation using counterpuncture ("through and through" or "double-wall") technique are illustrated in Figure 8.2. When blood appears in the hub (a), the IV cannula is advanced a few millimeters in order to transfix the artery and the needle is withdrawn. Then, the cannula is gently drawn back (b) until backflow reappears, and then a 0.018–0.021-inch. wire is introduced (c). For the new TRI operator, through-and-through access technique is preferable as it insures coaxial alignment of the IV within the RA once the needle is removed, minimizing the chances of the wire being directed against the wall of the vessel by the bevel of a micropuncture

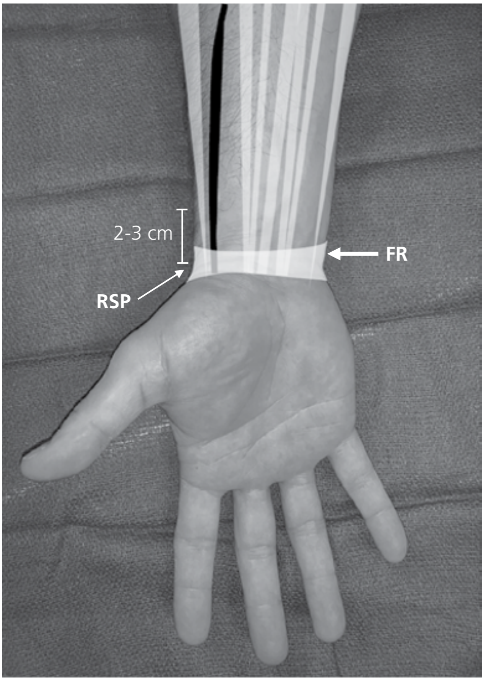

Figure 8.1 **Optimal puncture site for conventional (proximal) radial approach**. The radial artery (shown in red) should be punctured on the volar (palmar) aspect of the forearm, 2–3 cm proximal to the radial styloid process (RSP), taking care to avoid puncturing through the flexor retinaculum (FR, transverse carpal ligament) or traumatizing the ligaments of the forearm (relevant tendons from medial to lateral: flexor carpi ulnaris, flexor digitorum superficialis tendons (2), palmaris longus tendon, flexor pollicis longus tendon, flexor carpi radialis tendon, brachioradialis tendon) superimposed on this image for illustrative purposes. Excessively proximal (high) punctures risk traversal of the insertion of the brachioradialis muscle with resultant inability to achieve hemostasis. Source: Courtesy of the Cardiac Catheterization Laboratories, The University of Chicago Hospitals, Chicago, IL, USA.

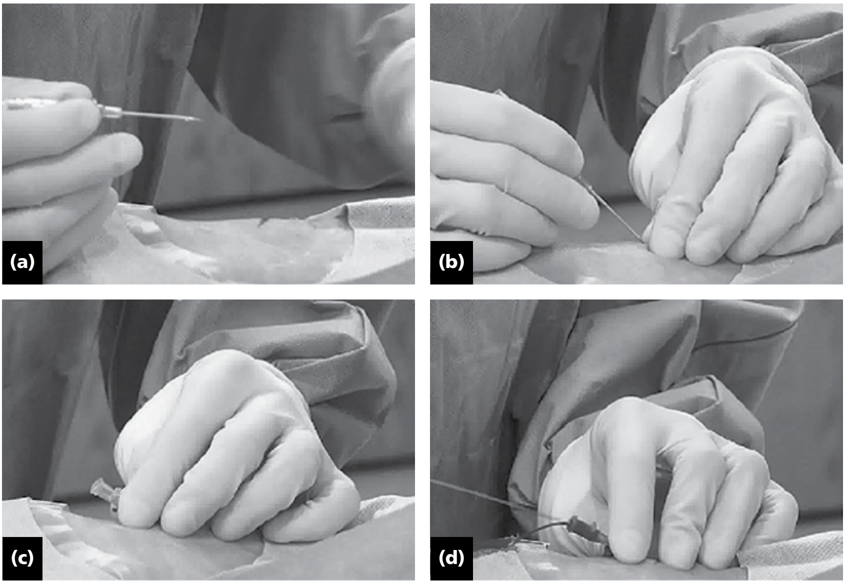

Figure 8.2 Approach to radial access using an angiocath/IV cannula and counterpuncture technique. In Panel A, the prepped forearm is extended slightly at the wrist and anesthetized at the optimal puncture site via lidocaine infiltration. The preferred angle of skin entry (Panel B) ranges between 30° and 60°, recognizing that shallower angles may potentially allow for a longer intraluminal trajectory of the beveled needle tip and easier sheath advancement than steep entry angles. Once blood return is noted in the needle hub, the angiocath/IV system is advanced through the back wall of the radial artery, transfixing the vessel in place; the needle is removed completely and the angiocath is withdrawn slowly (Panel C). Once pulsatile blood return is noted, the guidewire is introduced into the radial artery and advanced. Fluoroscopic guidance may be required if resistance is encountered upon wire passage. Source: Courtesy of the Cardiac Catheterization Laboratories, The University of Chicago Hospitals, Chicago, IL, USA.

needle. For the experienced operator, the technique of ONLY anterior wall puncture could be done without frequent failure and repeated attempt. Nonetheless, as with most techniques, the one most familiar to the operator may well prove to be the best option.

Tips and Tricks

****Where is the missing artery?** In a case of atrophic RA (RA is the terminal branch of the palmar arch), change the access site. Rarely, the radial artery is not at the right place, but it is on the lateral side of the wrist (very rare: 2/1000). So don't forget to check the pulse on the lateral side of the wrist.

Discriminating Differences

Right or left radial approach The choice between right and left radial approach (LRA and RRA) is more or less related to operator's preference. The LRA requires a different table setup and logistics. The RRA is more nurse-friendly as it requires standard equipment. It is also more operator-friendly because, unlike the LRA, it does not require leaning over the patient in order to manipulate catheters, wires, and devices. However, the LRA seems preferable for slim females with small, spasm prone radial arteries, especially in the presence of subclavian and/or brachiocephalic tortuosity. LRA is certainly the approach of choice when Allen's test is negative on the right radial or when a left internal mammary artery (LIMA) angiography is indicated. The RRA was found to be associated with minimally longer fluoroscopy times (5.8 ± 4.4 min versus 5.3 ± 4.2 min, SD of the mean = 0.157, $P < 0.001$) and greater contrast use (84 ± 35 mL versus 82 ± 34 mL, SD of the mean = 0.082, $P = 0.003$). Access site complications and the incidence of stroke were similar between two radial approaches.

Tips and Tricks

*****When left radial access is preferred** Short-statured patients, as well as patients with significant abdominal obesity, tend to have longitudinally compressed ascending aortas, and cannulation is often easier from the left RA. Evaluation and treatment of infra-diaphragmatic pathology is best performed from the left wrist as it provides ~10 cm of additional length. Left subclavian and left vertebral interventions are also straightforward from the left wrist. Finally, because left-sided radial procedures more closely mimic the femoral approach in terms of catheter manipulation and seating, operators, particularly those early in their learning curve, may find it easier for using more familiar femoral (Judkins) catheters [4].

Radial Sheaths

The most used sheaths are 5-Fr for diagnostic angiography and 6-Fr for intervention, but sometimes 4-Fr sheaths are needed for coronary angiography via small radial arteries and 7-Fr sheaths for complex interventions. The shorter sheaths seem preferable, and hydrophilic coating reduces friction in insertion and removal by 70% [5]. No skin incision is required with tapered sheaths. After insertion, a cocktail of verapamil 3 mg and 3000–5000 units of heparin are injected through the sidearm. The operator can use single drug preparations or spasmolytic cocktails. Verapamil 3 mg has been proved quite safe and effective. Previous radial catheterization does not diminish responsiveness to nitroglycerin and verapamil despite some reduction in the arterial lumen diameter. Exchange devices through a sheath may cause less spasm. Some operators have recommended that heparin should be administered *after* the catheter has crossed into the central circulation to avoid an anticoagulated state in the potential rare case of RA perforation.

Action for Advanced Operators

Access for occluded radial artery The wrist is prepared and draped in a standard manner, and after local anesthesia, a 20-gauge Teflon cannula is placed using through-and-through puncture in the very distal portion of the right RA, where a low-volume collateral flow pulse is usually palpable from the palmar arch. As the cannula is withdrawn, arterial blood is observed as a nonpulsatile dribble in the hub of the cannula. A 0.021-inch. wire (Terumo, Somerset, NJ, USA), which is a part of the Glide Sheath package, or a 0.018-inch. micropuncture wire (Cook Inc., Bloomington, IN, USA), is advanced into the cannula. By gentle maneuvering, the pulseless portion of the RA is traversed under fluoroscopic guidance to follow the imaginary path taken by the RA, though its painless advancement is almost completely guided by tactile feel. If wire advancement causes pain, the wire should be withdrawn and readvanced. A previous radial angiogram is a significant help and may serve as a roadmap. A long angiocath or micropuncture introducer (Cook Inc., Bloomington, IN, USA) is advanced over the wire with gentle torquing motion. After removal of the wire from the microcatheter, pulsatile flow should now be present. The 0.021-inch. wire is reinserted in the introducer and a Radiofocus Glide Sheath is carefully advanced.

The wire is advanced purely based on tactile feel. Gentle forward pushing with slow-torque application is the technique used for wire advancement. Close observation for even mild pain is required because false lumen passage will be associated with pain. Painless advancement of the wire with little or no initial resistance is a sign of true lumen entry [6].

SHARP THINKING

Advantages and Limitations

The limitations of this technique include the blind nature of the initial procedure, and hence the risk of subintimal wire passage and perforation. Careful attention to even mild pain caused by the wire movement will help avoid this complication. The other potential risk is the possibility of embolization of the thrombus. Careful aspiration and forward injection only after establishment of free back-bleed will help prevent this complication [6].

Action for Advanced Operators

Proximal radial access in patient with occluded radial artery A patient who had undergone prior right radial TRA PCI presented for a repeat angiogram and was found to have a positive inverse Barbeaus test suggestive of occluded RA. Distal RA pulse was palpable because of palmar arch collaterals. However, the RA was very faintly palpable higher up in the proximal segment. Ultrasound confirmed RA occlusion at the site of prior sheath placement with a patent and pulsatile RA more proximally in the forearm. After sterile preparation and draping in a standard fashion, a 20-gauge Teflon-sheathed needle was used to access the RA 7–8 cm proximal to the previous point of entry using ultrasound access. Upon entry into the lumen, a “flash” of blood was noted in the transparent chamber at the proximal aspect of the access needle. Counterpuncture technique was used, and the needle was advanced through the posterior wall. The stylet was then removed, a 0.021-inch. wire was placed in the hub of the Teflon cannula, and the whole system was gradually withdrawn. Upon the appearance of the blood flow, the wire was advanced with tactile feel. Resistance-free wire advancement was feasible and the Teflon cannula was removed. A 6-F radial introducer sheath (Radifocus, Terumo, Japan) was advanced over the wire. After removal of the dilator, the stopcock was opened and free pulsatile blood flow was observed. At this point, the sheath was flushed with saline and vasodilator cocktail, and unfractionated heparin was simultaneously administered intravenously [7] (Figure 8.3).

Advantages and limitations The “proximal entry” technique described above is well suited for the “focal” RA occlusion, where this technique does not disturb the thrombus and hence has a safety advantage. It could also be used in those patients where the first site of access was distal and hence a “stump” is not easily accessible. The potential drawbacks of this technique are its inability to recanalize the occluded portion of the RA, hence eliminating the probability of future patency. The other drawback of this technique is its proximal site of entry on the RA lumen, which may make subsequent hemostasis difficult to achieve as the RA traverses through the bellies of the surrounding muscles leading to inadequate compression pressure and suboptimal hemostasis. An optimal manual compression followed by serial observations over several hours should reduce the chances of significant hematoma.

The “distal entry” technique described in the past is feasible in either subset of patients, although it involves recanalization of the thrombosed RA segment and, hence, increases the risk of complications related to dislodgement and migration of the thrombus. This technique also has the benefit of removal of the occlusive “plug” increasing the probability of subsequent RA patency. This new technique should be added to the armamentarium of a radial operator allowing for reaccessing the occluded RA. The choice of the “proximal” or “distal entry” technique depends on the anatomical attributes as well as operator preference [7].

HEMOSTASIS

Hemostasis can be achieved simply with a roll of gauze and a couple of elastic strips (Figure 8.4) or with dedicated devices. Several of the latter pneumatic devices are transparent allowing visual control and has quantification of inflation, ensuring selective graded compression of the

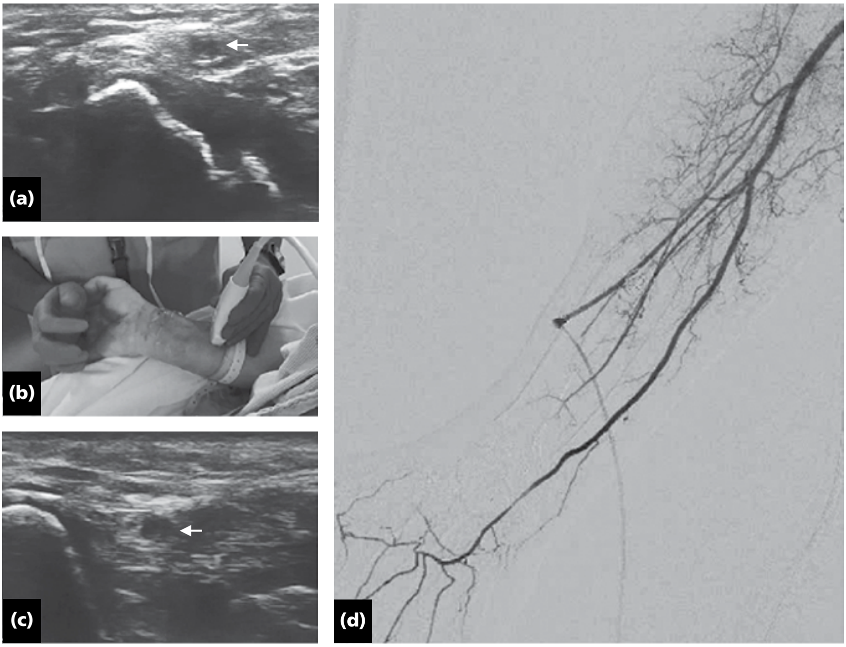

Figure 8.3 **Ultrasound-guided radial access in the setting of an occluded radial artery.** Lack of radial pulse and positive reverse-Barbeau test raised concern for radial artery occlusion after a prior TRA PCI. Ultrasound confirmed an occluded radial artery at the usual puncture site (Panel A, arrow) but a patent radial artery is more proximal in the forearm (Panels B and C). Ultrasound-guided puncture was performed at mid-forearm with the placement of a 6-Fr radial sheath (Panel D).

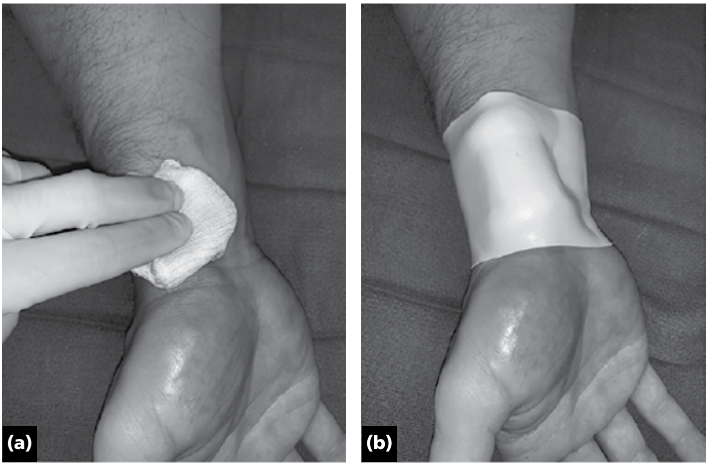

Figure 8.4 **Radial hemostasis using a compressive dressing**. Hemostasis may be initially achieved following sheath removal with manual compression over the puncture site using gauze. Subsequently, a pressure dressing may be applied as per institutional preference/protocols, using a gauze roll and medical tape or elastic adhesive dressing such as that illustrated in Panel B. While this approach is inexpensive and utilizes only commonly available supplies, it may be difficult to adapt to standardized protocols given that compression force will vary significantly based on materials used and application technique.
Source: Courtesy of the Cardiac Catheterization Laboratories, The University of Chicago Hospitals, Chicago, IL, USA.

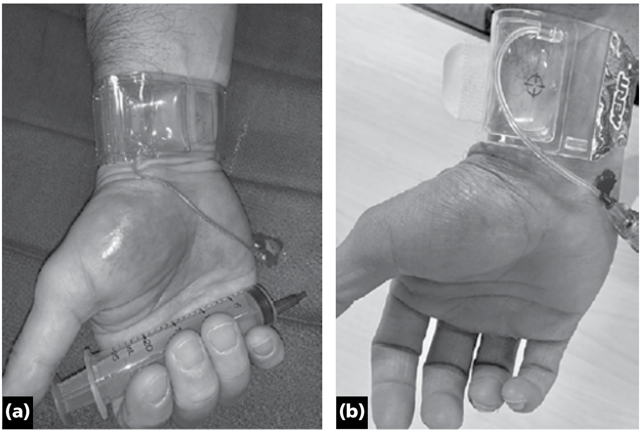

Figure 8.5 Radial hemostasis using a pneumatic compression device. Hemostasis of the radial puncture site is most often achieved via application of a manual (usually pneumatic) compression device, which allows for graded compressive force and the ability to maintain patent hemostasis, visibility of the puncture site at all times, and easy creation of institutional protocols. The Terumo TR band (Panel A) and the Merit Medical Sync band (Panel B) are shown. Source: Courtesy of the Cardiac Catheterization Laboratories, The University of Chicago Hospitals, Chicago, IL, USA.

RA without blocking blood return (Figure 8.5). Hemostasis typically takes 2–3 hours although rapid radial hemostasis protocols are currently in development.

WIRES

Usually the standard 0.025- or 0.035-inch (150–180 cm) J-wires are used to introduce catheters. The 0.025-inch. wire can be used for the cannulation of the RA, while the J-shaped 0.035-inch wire has the advantage of avoiding most side branches in the forearm and arm and providing better support. Advancing the wire around the shoulder of the patient should be done under fluoroscopy to ensure proper insertion into the ascending aorta without engaging side branches (carotids, vertebrals, mammary, etc.).

The common causes of resistance are (1) congenital anatomic variations such as the RA "loop," early origin of the RA, or an accessory RA, (2) tortuosity in the axillary, subclavian, or innominate artery (especially in older hypertensive patients), and (3) arterial spasm. Fluoroscopy should be utilized freely to avoid entering important branch vessels. If resistance is met with the J-wire, a second choice is a steerable 0.035-inch wire (e.g. Glidewire or Wholey™ wire). These wires are advanced under fluoroscopy with torquing performed as needed to avoid damage to small branch vessels. An angiogram of the arm may ultimately be necessary if the wire cannot pass easily (Figure 8.6).

Tips and Tricks

****External side compression of radial artery** In patients with unsuccessful advancement of wires into the brachial artery by the conventional method, a radial angiography should be performed with manual injection of nonionic contrast medium through the sidearm of the arterial sheath. When the wire keeps advance into the side branch or the RA is tortuous, external side compression of the RA at the culprit site could be performed with a finger of the second operator (Figure 8.7). When this attempt is unsuccessful, another angled hydrophilic wire should be tried as the next step. When the angled hydrophilic wire is not advanced into the brachial artery, the access site should be converted to brachial or femoral artery as the final step [8].

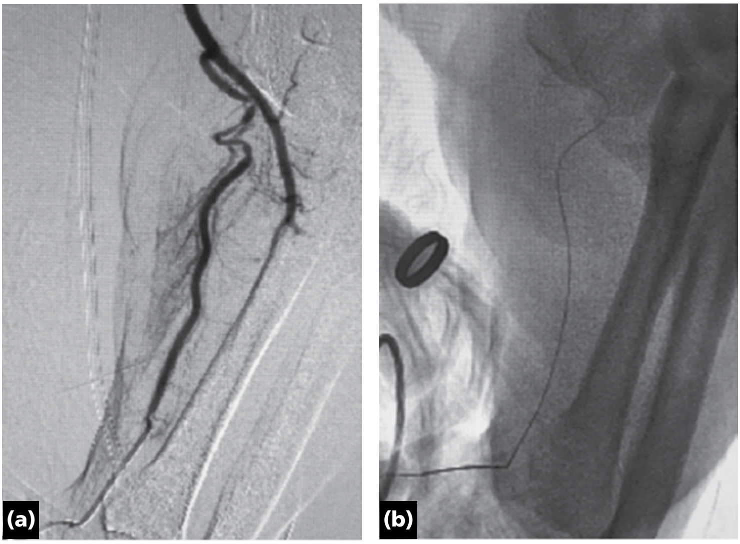

Figure 8.6 Difficulty with wire navigation through the forearm requiring angiographic guidance. Left distal radial ("snuffbox," ldTRA) puncture was performed using ultrasound guidance but neither a 21G nor 18G spring-tip wire would advance into the antecubital fossa. A 3-Fr micropuncture sheath was inserted into the radial artery over the 18G micropuncture wire and the angiogram shown in Panel A was taken revealing spasm and severe tortuosity. The micropuncture sheath was exchanged for a 5-Fr thin-walled radial sheath, a 0.035-inch Wholey wire used to navigate past the tortuosity and the case completed.

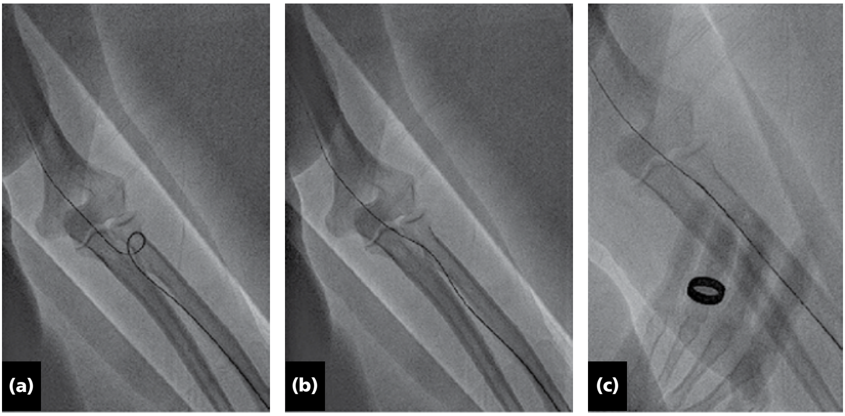

Figure 8.7 Challenges with crossing a partly tethered radial loop. A radial loop with associated recurrent branches was discovered on routine radioulnar angiography after left radial access was obtained. Initial crossing was attempted with a 0.035-inch Wholey wire which would not traverse the loop. Next, a 0.035-inch soft, angled Glidewire was loaded into a 4-Fr straight, tapered Glidecath and introduced into the radial artery. External manipulation was required to prevent entry of the Glidewire tip into the side branches, and the loop was crossed (Panel A) and partly straightened (Panel B). Resistance was encountered upon attempts to pass coronary catheters through the loop which was alleviated, once again, with external manipulation of the radial artery (gentle medial traction on the vessel at the point of resistance), and the case was completed uneventfully.

CATHETERS

Most operators still use the Judkins catheters for coronary angiography irrespective of the approach – RRA or LRA. This is probably due to the fact that most radial operators were originally trained to perform transfemoral angiography and feel comfortable with the Judkins catheters. In the Spaulding series of left TRA, there was high success rate for left coronary cannulation but a second catheter was needed for right coronary cannulation in every 10th patient [9]. Often successful left coronary artery (LCA) intubation is achieved with a Judkins left (JL) that is 0.5 size smaller than the one chosen for transfemoral angiography. In some cases with kinked truncus brachiocephalicus or left subclavian artery in combination with superior orientation of LCA, a choice of smaller Judkins catheter resolves the problematic intubation, i.e. JL 3.0.

Single Catheter

Use of a single diagnostic catheter may minimize frequent exchange of hardware and thus may reduce the incidence of spasm and catheter-induced cholesterol debris embolism. This also offers a cost benefit – one less catheter is used. Several types of "multipurpose" (MP) catheters like the Kimny (Boston Scientific, Marlborough, MA), Barbeau (Cordis, Miami Lakes, FL), or the Amplatz left (AL) catheter (Cordis, Miami Lakes, FL) can achieve exceptionally high success rate for both coronary arteries [4] (Figure 8.8 and Table 8.1).

Tips and Tricks

Manipulating the single catheter One useful technique when utilizing a non-MP catheter is to first engage the right coronary artery (RCA) by withdrawing the 0.035-in. wire only slightly, leaving the tip just distal to the secondary curve (or tertiary curve, in case of the Kimny catheter). This maneuver straightens the secondary curve, thereby approximating the shape of a Judkins right (JR). After right coronary angiography, the catheter is slightly

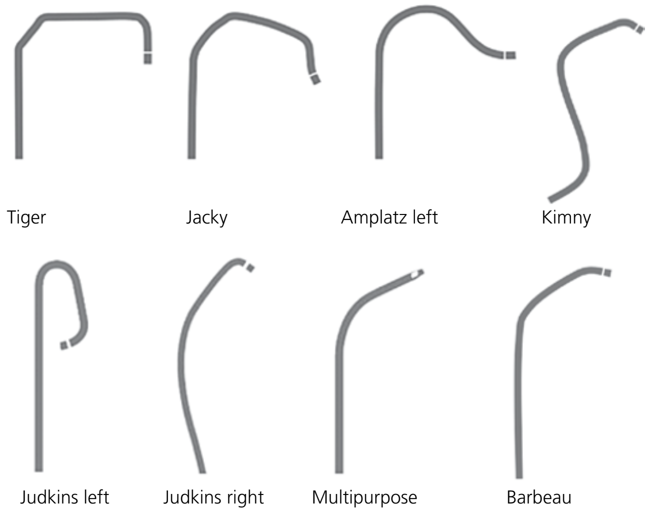

Figure 8.8 Commonly used TRA catheter curves. Several classic catheter curves used in transradial angiography and intervention. Some such as Tiger, Jacky, Amplatz, Kimny, Multipurpose, and Barbeau are intended as universal catheters, while others such as Judkins curves are meant to engage specific coronary arteries. It should be noted that variations on these basic curves are now offered by multiple manufacturers.

Table 8.1 **Catheter shapes for transradial diagnostic and/or interventional procedures**

Diagnostic (universal)	Diagnostic (LCA, RCA)	Guide (universal)	Guide (LCA)	Guide (RCA)
Kinmy	JL 3.5, JR 4.0	Kimny	Ikari left	Ikari right
Tiger	–	MAC 30/30	LARA	MRESS
Jacky	–	Barbeau	MRADIAL	RRAD
Sones	–	PAPA	Easy radial left	Easy radial right
MAC 30/30	–	–	–	–

withdrawn with counterclockwise torque to engage the LCA. Additionally, at times, multiple manipulations may result in "curling up" of the catheter in the aortic root. In this situation, the straight, rigid end of the 0.035-inch wire can be carefully advanced to a couple of millimeter distal to the secondary curve to straighten out the catheter. Care must be taken to never advance the straight wire tip beyond the catheter tip.

Advancement of Catheters

If the wire or catheter does not advance easily, the operator should be aware of several possibilities: spasm, small RA, loops, high take-off (sometimes as high as axillary origin), remnant artery, stenosis (radial, brachial, subclavian), wire in a side branch.

Tips and Tricks

*****How to overcome the problems of loops, remnants, high take-off** Loops are relatively frequent and located in the forearm, arm, and brachiocephalic segment. They represent different congenital and acquired anatomic conditions, and most of them can be overcome with experience [10]. The really difficult ones are in the RA, sometimes with higher take-off (axillary, brachial) or with radioulnar anastomoses. The infrequent extreme loops that are generally accompanied by a remnant pose a real challenge to the operator and furthermore increase the risk of perforation. If you encounter a loop, do angiography through the sheath or catheter. Advance gently a hydrophilic 0.025-inch J-wire or 0.014-inch percutaneous coronary intervention (PCI) wire under angiographic control. This will usually solve the problem. Use a 4-Fr relatively straight catheter (e.g. MP or Glide catheter (Terumo, Somerset, NJ, USA) (Figure 8.9).

****What to do when encountering a problem with aorto-subclavian tortuosity? Don't panic. Use the magic trick: ask the patient to take a deep breath** If the wire goes only in the descending aorta, push guide in the descending aorta, pull wire, and then slowly withdraw the guide and direct it into the ascending aorta with a counterclockwise rotation. Severe subclavian-innominate artery tortuosities and distal origin of the innominate artery result in a decreased forward force and increased friction during the progression of the wire or guide toward the ascending aorta. Use of a floppy steerable wire such as a Wholey wire or a hydrophilic wire may help traverse the segment. If initial attempts are not successful, use of an angioplasty wire combined with deep breath frequently resolves the problem (Figure 8.10).

Tips and Tricks

****How to overcome tortuous arteries** In cases of subclavian/innominate artery tortuosity, it may be beneficial to leave a 0.035-in. wire in the catheter while torquing the catheter into place. RCAs with an inferior take-off from the aorta often pose a problem due to the tendency to engage the conus branch (CB). This may also be alleviated by straightening the shaft of the

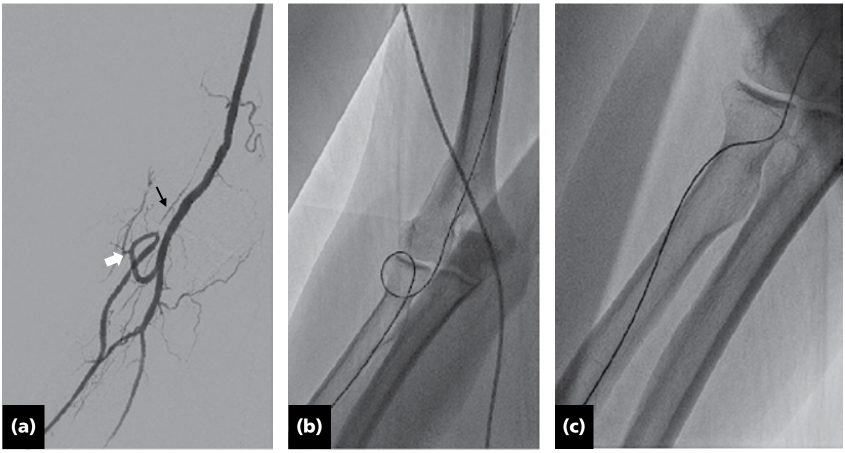

Figure 8.9 Crossing a radial loop. A radial loop (Panel A, white arrow) along with a small recurrent radial branch (black arrow) was discovered on radioulnar angiography. The loop was crossed easily with a soft, angled Glidewire (Panel A) and partially straightened with a 5-Fr MP catheter (Panel C). After this, a 260-cm exchange J-wire was introduced with complete straightening of the loop and the case was completed with Judkins catheters.

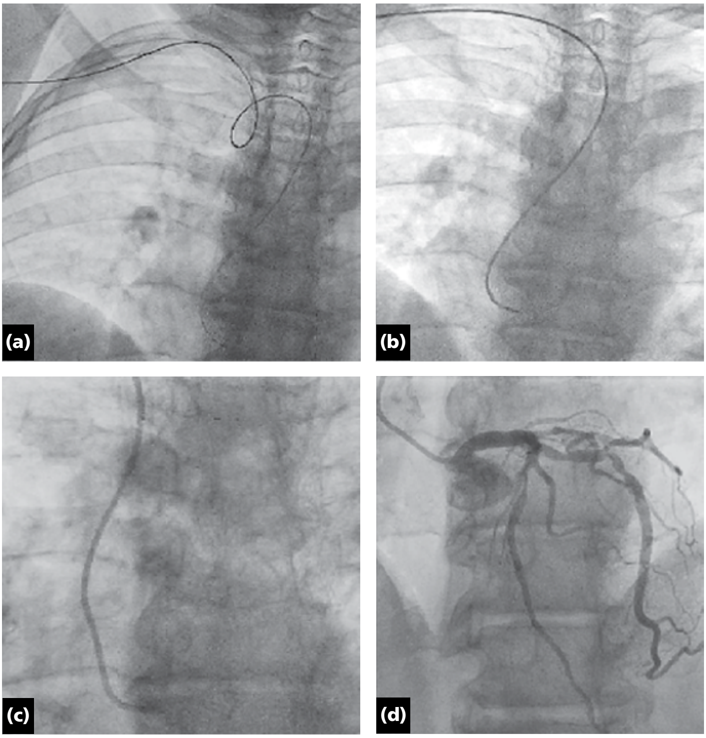

Figure 8.10 Subclavian tortuosity combined with angulation at the aortic-brachiocephalic junction. A 0.035-inch Wholey wire is used to traverse the subclavian loop (Panel A). After a guiding catheter is advanced, traction is placed on the entire system to straighten the loop (Panel B). The JL 3.5 guide is manipulated counterclockwise while the patient inspires deeply (Panel C) to seat the guide in the left main coronary artery (LMCA) ostium (Panel D).

catheter by introducing a 0.035-in. wire in the catheter and engaging the RCA. When these catheters are used for left ventriculography with power injection, a lower pressure ($\leq$350 lb./in^2) is recommended because the presence of a single side hole does not significantly reduce the force of flow through the distal tip that could result in serious trauma to the left ventricle [4].

Limitation Due to Anatomic Variations

There are a number of variations in the origin and distribution of the brachiocephalic trunk, including the bicarotid trunk and the rare retroesophageal right subclavian artery (arteria lusoria), which cause problems to the advancement of the catheter from a RRA. Other limitations include stenosis, hypoplasia, radioulnar loop, and abnormal origin. The arteria lusoria is a congenital anomaly in which the right subclavian artery arises from the descending aorta just below the arch or the arch junction. So many times, the right subclavian is lateral to the left subclavian (Figure 8.11).

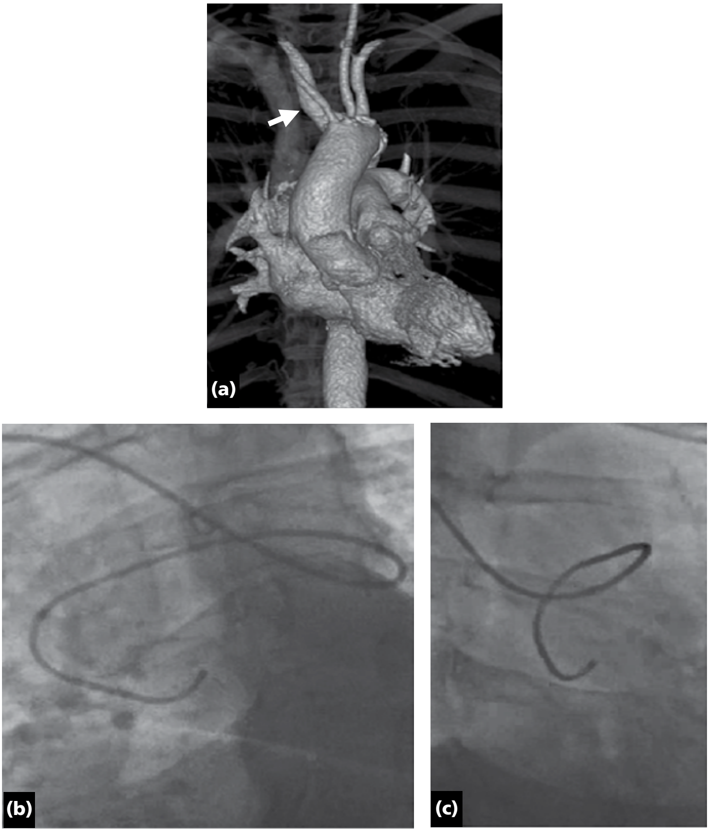

Figure 8.11 **Arterial lusoria (aberrant, retroesophageal right subclavian artery).** Panel A shows a computed tomography angiography (CTA) of the aorta with three-dimensional surface rendering demonstrating an aberrant right subclavian artery (arrow) that branches from the aorta, distal to the left subclavian artery. A 0.035-inch Wholey wire was advanced into the descending aorta from right radial approach. Next, a Cobra C1 catheter was advanced over the wire into the proximal descending aorta, rotated clockwise, and pulled back until aimed at the transverse aortic arch. A 0.035-inch in soft, angled Glidewire was advanced into the aortic root, and a JL 3.5 catheter was advanced into place over the guidewire (Panel B). The RAO view (Panel B) demonstrates the course of the aberrant vessel.

Tips and Tricks

*****Arteria lusoria** When arteria lusoria is suspected, an aortic arch injection with the camera in 30°–45° LAO angulation will help define the anatomy of the aortic arch and great vessels (Figure 8.11). In true cases of arteria lusoria, the 0.035-in. wire will invariably advance into the descending aorta from a RRA. A useful technique is to advance a JL catheter or a Cobra C1 catheter over the wire, just distal to the aortic arch. The wire is then withdrawn into the guide catheter and counterclockwise catheter torque exerted with deep inspiration and advancement of wire. This maneuver will frequently result in access into the aortic root.

Learning Curve

Limitations of the radial approach are the longer learning curve and lower rate of procedural success compared to the femoral approach. Proper patient selection is important at the beginning of the learning curve: it is preferable to start with large, easy-to-puncture arteries and simple cases and gradually progress to more difficult ones in terms of access and interventional complexity. Factors that predict TRA failure are female gender, low body mass index (BMI), advanced age, and lack of experience. At the beginning of the learning curve (the first 500–1000 transradial procedures), it seems reasonable to exclude patients with weak pulses, low BMI, and complex interventions such as PCI for primary angioplasty, bifurcations, and chronic total occlusions (CTOs). After the inherent learning phase, the TRA failure rate is very low (about 1%), the reasons being mainly anatomic difficulties [11].

ALTERNATIVE ACCESS SITES

Ulnar Approach

The ulnar artery as an access site was an acceptable alternative with much lower success rates compared with TFA and TRA. The mean success rates were between 38% in intention-to-treat strategy patients and 100% in highly selected cases. The lower success rates can be explained by (1) the much deeper location of the ulnar artery, which at times lies around or just below the tendon of the muscle flexor carpi ulnaris; (2) the absence of a good bone base as in the RA (so hematoma can occur); and (3) the close proximity to the ulnar nerve, which can make puncture very painful [12]. To avoid hand ischemia, this site should be avoided if initial radial access attempts have potentially compromised radial perfusion.

GUIDES

In guide selection for TRI, the operator should consider factors such as target lesion features, lesion location, the presence or absence of proximal tortuosity, size of the ascending aorta and location of the coronary ostium, distal origin of the brachiocephalic trunk from the aortic arch, and subclavian–brachiocephalic tortuosities. Extensive manipulation of guides may provoke spasm, especially in anxious patients or those with small radial arteries or anatomic difficulties. Most coronary interventions are performed through 6-Fr guides, but in many patients 5-Fr or 7-Fr and 8-Fr guides can be used if necessary [13]. Appropriate guide choice is even more critical with TRI than with TFA. Selection and manipulation of these shapes is somewhat different when compared to transfemoral intervention (TFI).

Guides for Left Coronary Artery

When a JL 4 is used in patients with a vertical and normal-sized aorta, the resultant backup support is 1.6 times lower than that provided by the same guide used transfemorally. The point of contact with the contralateral aortic wall during right TRA moves further up above the left coronary ostium, which results in reduced backup force. That is why experienced operators use

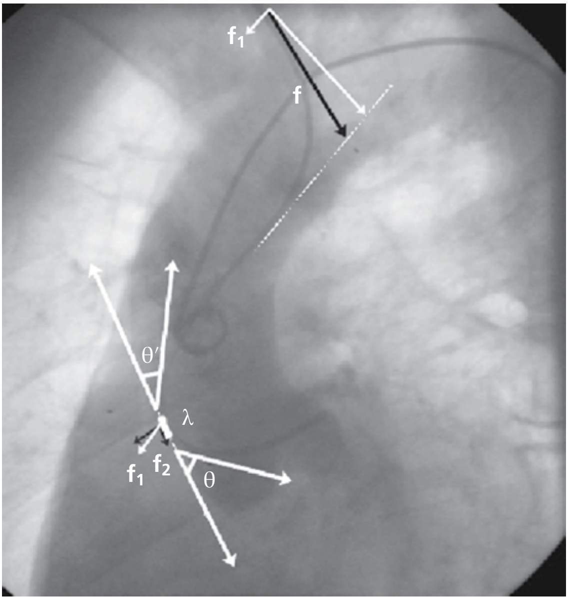

Figure 8.12 Mechanisms of backup and pushing force according to positions and properties of the guide. Courtesy of Dr. Yuji Ikari.

a JL 3.5 guide, which provides better support. A JL is an appropriate guide in the setting of noncomplex lesions or in left main (LM) stenosis, where good support is not a critical factor [14] (Figure 8.12).

When the target artery is the left circumflex (LCX), a 0.5 larger size is preferred for better coaxial alignment. If active support is deemed necessary, deep-seating for the left anterior descending (LAD) can be achieved with a 5-Fr short-tip JL. This maneuver should be accomplished over the shaft of a balloon or stent with the assistance of deep inspiration and an apparent lack of LM or ostial LAD disease [14].

Extra-backup guides provide greater support than JL, due to the larger contact area and the almost right angle with the opposite aortic wall. An inherent drawback of extra-backup guides is the tendency for deep intubation of the LAD or LCX in the presence of a short LM. In cases of complex LAD or LCX angioplasty and long LM, wide bifurcation angle, or extreme proximal tortuosity, the EBU guide often becomes the first choice [14].

Tips and Tricks

****When cannulation of the LCA becomes difficult** An AL 1.5 or 2.0 is suitable for complex lesions of LCX and provides greater passive support. Because of the downward-pointing AL tip, the operator should pay attention to prevent dissection caused by deep intubation when pulling the balloon or catheter out of the ostium [14].

****Cannulation of the LCA in patients with dilated and unfolded aorta** Cannulation of the LCA ostium and obtaining optimal backup support might be fairly difficult in patients with a dilated and unfolded aorta. In cases with distal origin of the innominate artery, the guide approaches the LCA more from the left and this encumbers manipulation. Deep inspiration, leaving the wire in the guide during maneuvering, or choosing guides with a brachiocephalic curve, may help in this setting.

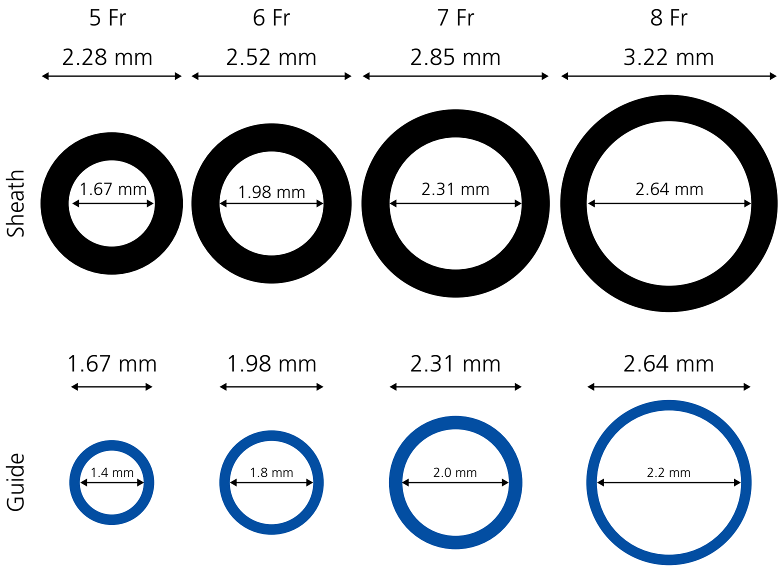

Figure 8.13 Differences in internal and external diameters of sheaths and guides.

Guides for Right Coronary Artery

The first-choice guide for noncomplex or ostial RCA lesions is the JR in sizes similar to the ones used for TFI. In cases of dilated aorta, there is a lack of contact area with the opposite aortic wall, which results in poor support. The 5-Fr JR and MP are suitable for deep-seating or the so-called guide "amplatz-ing." Indeed, optimal support can be achieved with the AL catheter, but the operator should be extremely careful not to cause dissection with the traumatic AL tip. After overcoming the learning curve, the operator becomes quite confident with most femoral curves for interventions via the right TRA.

Radial Artery Diameter for TRI

A frequent argument against the TRA has been techniques and device incompatibility for complex coronary interventions. The mean radial diameter was 3.10 ± 0.60 mm and 2.80 ± 0.60 mm in Japanese males and females, respectively. The cumulative relative frequency of RA diameter shows that 5-Fr introducers can be used in 93% of patients, 6 Fr in 85% of males and 72% of females, 7 Fr in 71% of males and 40% of females, and 8 Fr in 45% of males and 24% of females [13] (Figure 8.13).

As the majority of coronary interventions today are performed via 6-Fr guides, it is obvious that there are no substantial restrictions to the radial route. The same is true for many devices such as intravascular ultrasound (IVUS), a certain range of rotablation (ROTA) burrs, the cutting balloon, and dedicated thrombectomy catheters. When in doubt, the operator can determine the radial diameter by angiography or echography. If the TRA is incompatible with the intended technique or device, one obviously has to switch to the TFA.

Tips and Tricks

****Advancement of guide through tortuous subclavian artery** The operator must be very cautious when crossing tortuous subclavian segments because of the proximity and risk of damage to the carotid and vertebral arteries. Use of one or two PCI wires with careful manipulation overcomes most of the curves. Sometimes, two diagnostic wires could be used.

The main purpose is for the catheter to reach the aortic arch. Alternatively, a 110- or 125-cm long diagnostic catheter is inserted into the guide (mother-in-child technique), and the assembly is carefully advanced into the aorta. Once the catheter tip is in the aorta, the catheter is rotated counterclockwise with simultaneous advancement of the wire. A very useful tip is to ask the patient to take and hold a deep breath and to turn their head to the left. If these maneuvers do not help, sometimes a small (4- or 5-Fr) diagnostic catheter can be advanced into the ascending or descending aorta and the combined guide catheter can be advanced over an extra-stiff 260-cm Amplatz wire. These maneuvers work equally well in the RRA or LRA. If the operator selects the LRA, a specific tip to enter the ascending aorta, once the catheter is in the descending aorta, is to pull the wire inside the JL guide and then to direct the flexed catheter with its second curve to the ascending aorta. When the target is reached, the wire is introduced to straighten the catheter and to engage the coronary artery. The insertion of a very long sheath also helps to cross a very tortuous subclavian artery [15].

WARNING
The extra-stiff wire can be used only when the catheter or guide is in the aorta. Do not cross the tortuous subclavian artery with an extra-stiff wire because it can cause dissection of the subclavian artery.

CORONARY CANNULATION

Left Coronary Artery

The catheter is advanced into the aortic root toward the left coronary sinus (LCS) in the anterior–posterior (AP) view, with the tip directed to the left of the screen. It is important that the tip is not deeply seated in the sinus. Slow and gentle clockwise rotation of the tip up to around 40°–50° usually leads to engagement of the LCA ostium. If this fails, the catheter tip is rotated counterclockwise and slightly withdrawn until it eventually pops into the LCA ostium. Aimed to reduce catheter tension, this maneuver increases the success rate to over 90%. In the event of a second failure, clockwise rotation from a higher sinus location and slight withdrawal of the catheter usually enables successful cannulation of the LCA.

Tips and Tricks

****Taming the tiger** In patients with a small ascending aorta and tip pointing downward, the Tiger catheter (Terumo, Tokyo, Japan) must be pushed down into the LCS and then be bent upward while being rotated counterclockwise toward the LCA ostium. With a dilated ascending aorta, the catheter must be rotated toward the LCA ostium with the wire tip between the primary and secondary curves of the Tiger catheter. This usually prevents the catheter bouncing upward into the dilated aorta. In cases of LCA cannulation failure, the Tiger catheter should be substituted for catheters with different curves (JL, AL). If still unsuccessful, the companion Jacky catheter, which features an "Amplatz-like" tip, may provide a useful alternative.

Right Coronary Artery

Following LCA angiography, the catheter is withdrawn from the LCA ostium and rotated counterclockwise in the left anterior oblique (LAO) view so that the perpendicular segment formed by the primary and secondary curves disappears on the screen. At this moment, a gentle push would direct the tip into the noncoronary sinus (NCS). Upon slight withdrawal and clockwise rotation, the catheter tip turns into the right coronary sinus (RCS) and engages the RCA ostium in a similar fashion to the JR and AL technique.

Tips and Tricks

****If the Tiger keeps going into the conus?** If the catheter stubbornly enters the CB, a slighter and more discrete clockwise rotation can be repeated, accompanied by a short pull-back. This maneuver prevents supraselective intubation of the CB. Alternatively, the curve could be straightened with a wire tip, thus resembling the JR curve, and/or the RCA ostium approached from a higher sinus position. Sometimes, the problem can be solved with deep inspiration. If all that fails, the Tiger should be exchanged for a JR catheter.

****Manipulation of the Q curve guide for both right and left coronary artery**
Q guides (Merit Medical, South Jordan, UT, USA) are all size 6-Fr (Q3.5 and Q4 curves, Mach 1™ type). The guide is advanced through the arteries of the arm to the aortic root with the wire leading. On entering the level of the coronary ostia, the wire is retracted into the guide and the guide is manipulated into position. For the LCA, this typically requires the wire tip to be several centimeters short of the guide tip and for the guide to be advanced while being rotated counterclockwise to engage the left coronary ostium. For the RCA, the wire is advanced to rest in the RCS, located anteriorly in a LAO view. The guide is then gently advanced over the wire until it reaches the level of the RCA sinus. The wire is then retracted slowly while the guide is advanced and rotated gently clockwise until it engages the coronary artery or allows suitable imaging by virtue of its proximity to the vessel's ostium. If the proximal portion of the RCA appears to have a suitable shape and take-off from the aortic root, the wire is then gently retracted further to allow the Q catheter to adopt its preformed shape [16].

Discriminating Differences

The Mach 1 Q guide (Merit Medical, South Jordan, UT, USA) is an excellent default device for LCA PCI, having a good balance between manipulability, backup support, and capacity for deep engagement of the coronary while being atraumatic to the coronary ostium and LM stem. This guide has a relatively soft and easily deformable distal curve, reducing the risk of trauma and dissection at the vessel ostium. For the RCA, the Q shape might seem somewhat excessively curved. However, the Mach 1 Q guide fits the RCA well via the radial route, especially if the artery is of flat or upturned origin. Even if the guide is not ideally suited to the RCA take-off from the aortic root, maintaining a 0.035-inch wire inside the guide (within an enclosed circuit including connected pressure wire and contrast lines) straightens the Q guide sufficiently to "look at" the RCA and assess the most suitable guide shape. Most other brands of the guide are either too rigid to take the shapes required to engage both coronaries or are too specifically shaped for either the left or right coronary. The Q guide can be used as the intended device for imaging both left and right coronaries and treating the culprit vessel. The crossover rate to a second guide is low and is usually a result of a downturned or aberrant RCA origin.

There are other guide shapes that might facilitate access to the right and left coronary arteries; the All Right and Kimny catheters are good examples. It is also possible to use an AL guide to access both coronaries. The operator has found this approach acceptable on occasion but has previously found that the Amplatz 1 is slightly too short in its distal curve to engage the left coronary with good backup support while the Amplatz 2 provides good backup for the left but is overaggressive on initial engagement of the right.

The particular combination of shape and distal curve rigidity of the EBU catheter used in this unit is problematic when engaging the right coronary (the tip remains too upturned, even with a wire in situ) [16]. The versatile Ikari Left guide catheter (Terumo Medical Corporation, Somerset, NJ, USA) offers excellent support for most left as well as right coronary anatomies. Again, caution should be exercised in case of deep ostial intubation.

Venous and Arterial Bypass Grafts

LIMA and right internal mammary artery (RIMA) angiography can be easily performed with the Tiger, JR, or Internal Mammary catheter from the ipsilateral RA. Most saphenous vein grafts (SVG) can be easily cannulated with the Tiger, JR, or JL catheters via the right TRA. Frequently, the insertion of a wire in the catheter is helpful. The wire can be advanced for RCA grafts or pulled to the secondary curve for lower inserted left grafts (diagonals) and then pulled all the way back for high take-off LCX graft ostia. When the Judkins catheter fails, the best option is probably the AL catheter.

Tips and Tricks

*****Intubation of the LIMA from the right radial approach (1)** From the right RA, advance the JR 4 and a wire into the left subclavian artery, left brachial artery, and left RA. Perform an external compression of the wire. This maneuver allows exchange of the JR 4 for a LIMA catheter and its advancement into the subclavian artery to perform selective LIMA angiography [15].

*****Intubation of the LIMA from the right radial approach (2)** From the right RA, advance a wire into the left subclavian artery, left brachial artery, and left RA. Ask the patient to flex the arm. Advance the Simmons I catheter (Cordis, Miami Lakes, FL, USA) or the Tiger into the subclavian.

*****The 0.035-inch wire is your friend** In most cases of difficult guide catheter manipulation or cannulation, the 0.035-inch wire can be useful for enhancing torquability, as well as straightening out the secondary curve. When inserted through a Tuohy Borst adapter, adequate contrast injection for test imaging can be performed to avoid repeated wire removal.

PCI Without a Radial Sheath

Working through the RA using a 7-Fr guide catheter may be challenging because of higher incidence of local pain and discomfort for the patient and significant resistance to the movement of a catheter and/or a wire. Minimizing trauma upon insertion of a large-lumen guide into the RA is key to success with such an approach. A custom-made commercial guide system with a hydrophilic coating and a long tapered central dilator is also available for seamless transitioning between wire, dilator, and guide for atraumatic entry into the RA. However, these devices are expensive and not universally available.

Tips and Tricks

Pseudo-taper techniques For easier insertion of the guide, a pseudo-taper was created for the guide by one of the five techniques:

1. Insertion of a 5-Fr × 125 cm Shuttle Select diagnostic catheter through a 6-Fr guide, inserted through the skin into the RA over a 0.035-inch standard J-tip Emerald™ diagnostic wire.
2. Insertion of a long (125-cm) 5-Fr MP Infiniti® diagnostic catheter (Cordis, Milpitas, CA, USA) into and through a 6-Fr guide over a 0.035-inch wire.
3. Insertion of a 5-in-6 GuideLiner® catheter (Teleflex Incorporated, Wayne, PA, USA) over a 0.035-inch wire.
4. Insertion of the dilator from a 4-Fr 110-cm sheath into a 5-Fr Launcher® guide.
5. Insertion of a partially inflated coronary balloon inside the tip of a guide over a stiff 0.014-inch exchange-length interventional wire [17] (Figure 8.14).

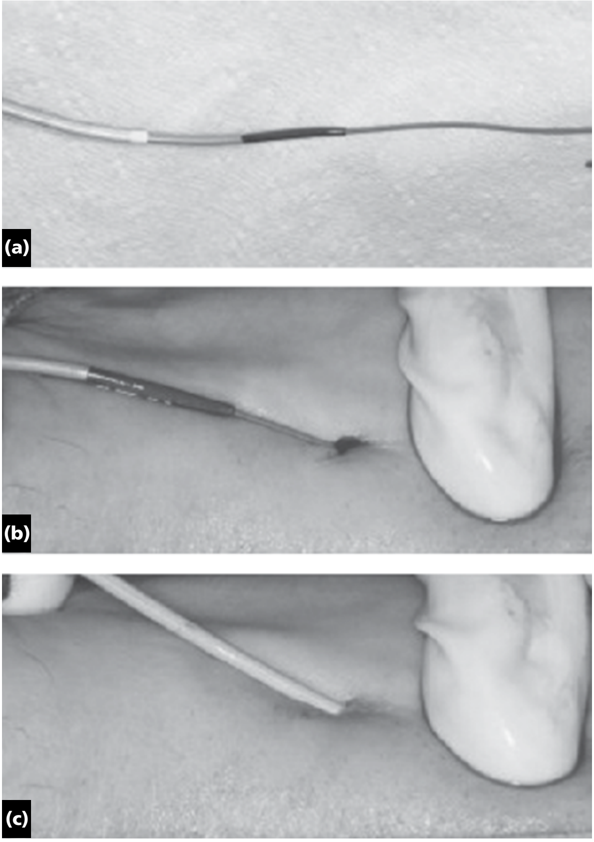

Figure 8.14 Tapering of a standard guide for sheathless insertion in the radial artery using a telescoping shuttle select diagnostic catheter. Insertion of a 5 Fr × 125 cm Shuttle Select diagnostic catheter through a 6-Fr guide (a), inserted through the skin into the radial artery over a 0.035-inch standard J-tip Emerald diagnostic guidewire (b), allows for sheathless insertion of a 6-Fr guide (c). Source: Reproduced with permission from [18] / John Wiley & Sons.

DEDICATED EQUIPMENT

E

The SheathLess Eaucath Guide System

This system does not require the use of a sheath introducer during PCI. It is available in 6.5-Fr (inner diameter 0.070 inch), 7.5-Fr (inner diameter 0.081 inch), and 8.5-Fr (inner diameter 0.090 inch) sizes. The SheathLess Eaucath 6.5 Fr (Asahi Intecc, Seto, Japan) possesses about the same Asahi Intecc, diameter (OD, 2.16 mm) as a common 4-Fr sheath introducer (2.0 mm), and the 7.5 Fr has a lower OD (2.49 mm) than a 6-Fr sheath introducer (2.62 mm) (Figure 8.15). The hydrophilic coating of the whole catheter enhances its trackability in tortuous vessels, reducing the risk of arterial spasm during catheter manipulation. The catheter insertion involves initial radial cannulation using a standard 5-Fr or 6-Fr sheath that is used to insert a standard J-tipped 150-cm × 0.035-inch diameter exchange wire. A spasmolytic cocktail to reduce radial spasm was not routinely used and in case of artery spasm after the sheath insertion, direct arterial injection of nitrates or verapamil was performed. The sheath is then removed, and the catheter (with its dilator) is passed over the exchange wire into the RA (Figure 8.16). Once the catheter has reached the proximal ascending aorta, the central dilator and the wire are removed and the catheter is advanced to achieve coronary intubation. Because of its stiffness, extreme care needs to be taken not to advance the central dilator close to the aortic valve.

Following coronary intubation, the SheathLess guide is fixed to the forearm at the RA entry point with a transparent sticky membrane to avoid slippage during the procedure. If catheters need to be exchanged during the procedure, they are exchanged over a 150-cm × 0.035-inch J-tipped wire [**19**].

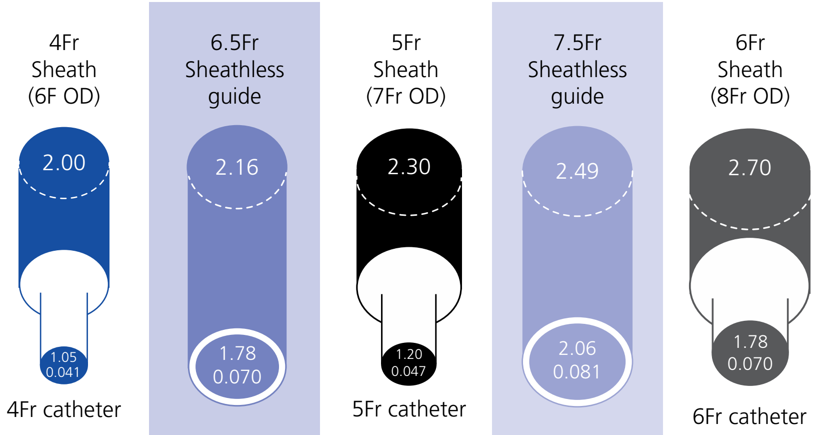
4Fr
Sheath
(6F OD)
2.00
1.05
0.041
4Fr catheter
6.5Fr
Sheathless
guide
2.16
1.78
0.070
5Fr
Sheath
(7Fr OD)
2.30
1.20
0.047
5Fr catheter
7.5Fr
Sheathless
guide
2.49
2.06
0.081
6Fr
Sheath
(8Fr OD)
2.70
1.78
0.070
6Fr catheter

Figure 8.15 Example of a sheath to guide comparison. In this example, the outer diameter of a 7-Fr guide is similar to that of a 5-Fr sheath but allows for a larger internal diameter. Source: Reproduced with permission from [20] / John Wiley & Sons.

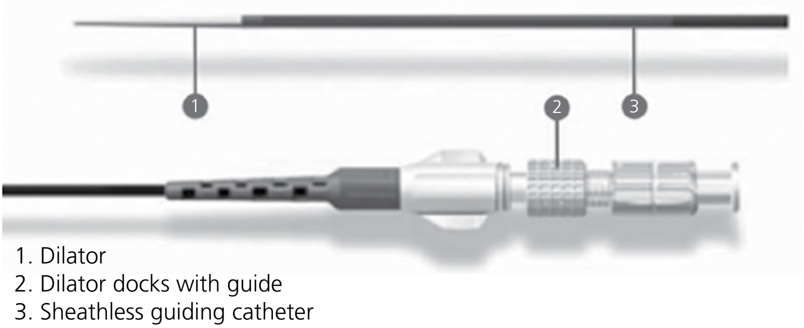
1
2
3
1. Dilator
2. Dilator docks with guide
3. Sheathless guiding catheter

Figure 8.16 ASAHI Sheathless Eaucath guide. Source: Reproduced with permission from [20] / John Wiley & Sons.

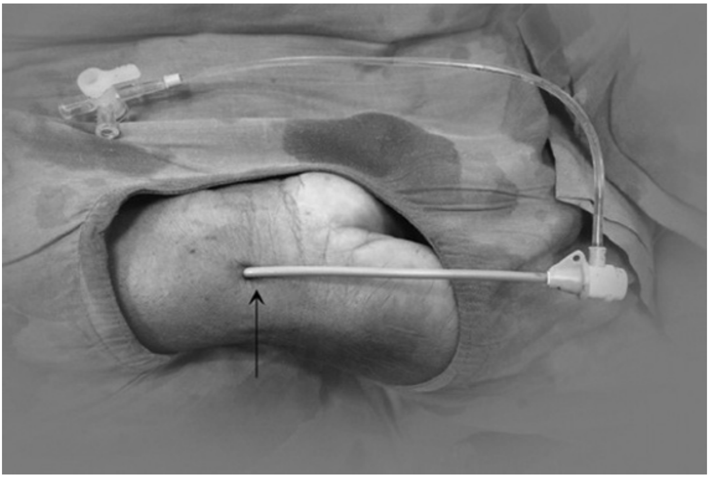

Figure 8.17 A partially introduced 7-Fr introducer sheath (virtual sheathless system; arrow). Source: Reproduced with permission from [21] / John Wiley & Sons.

Tips and Tricks

Virtual sheathless guide system The goal is to use standard available equipment to fashion an inner dilator for a standard guide and to prepare a modified mother-and-child system, which should help prevent RA injury and perforation and hematoma and local pain by eliminating "razor effect." The plan is to use a 7-Fr introducer sheath with minimal entry inside the RA lumen to create a virtual sheathless guide system, which should help reduce RA spasm and RA occlusion by minimizing the segment of mismatch between RA and introducer sheath (Figure 8.17).

The ODs of 7-Fr guides from different manufacturers, i.e. Medtronics (Launcher), Boston Scientific (Mach I), Terumo (Heartrail II), and Cordis (VISTA BRITE TIP®), are 2.39, 2.40, 2.37, and 2.3 mm, respectively. Moreover, the ODs of the 6.5-Fr and 7.5-Fr SheathLess Eaucath guides are 2.16 and 2.49 mm, respectively. This clearly shows that there is no significant difference in ODs of different brands and there should not be any compatibility issues with any of them. RotaGlide™ or ViperSlide™ lubricant solutions may at times help in difficult situations to facilitate the passage of large-bore guide catheters that do not have a hydrophilic coating. Once the guide is cannulated in the culprit artery lumen, the introducer sheath can be sleeved over the shaft of the guide to convert it into a completely sheathless system (Figure 8.18). This is an optional step of the technique, as in case of significant pericatheter oozing, the introducer sheath may be partially reintroduced to stop it. However, minimal pericatheter oozing can be controlled with a light compression band or gentle manual pressure. The "combo" technique is a unique combination of virtual sheathless and modified mother-and-child techniques that facilitates easy and painless tracking of a 7-Fr guide catheter for demanding coronary and peripheral interventions during TRA (Figures 8.19 and 8.20).

Tips and Tricks

Balloon-assisted tracking technique The balloon-assisted tracking (BAT) technique is used to increase the success rate of diagnostic procedures and PCI during TRA without damaging the vasculature. The BAT technique has been used to increase the success rate of TRA in difficult vascular anatomy including very small RA (diameter < 1.5 mm), significant RA tortuosity, complex RA loops, severe and resistant RA spasm, and subclavian tortuosities. It involves the use of a percutaneous transluminal coronary angioplasty (PTCA) guidewire and a PTCA balloon catheter. However, the "combo" technique involves use of an additional 5-Fr long

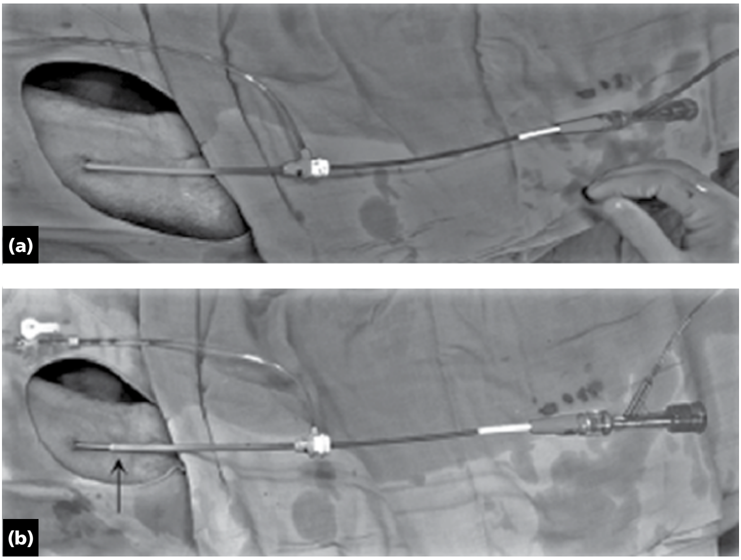

Figure 8.18 Demonstration of virtual sheathless technique. (a) A 7-Fr guide catheter has been introduced through a partially inserted 7-Fr introducer sheath. (b) Once the LCA was cannulated with a 7-Fr EBU 3.5 guide catheter, the introducer sheath was sleeved over the guide catheter to make it completely sheathless (arrow). Source: Reproduced with permission from [21] / John Wiley & Sons.

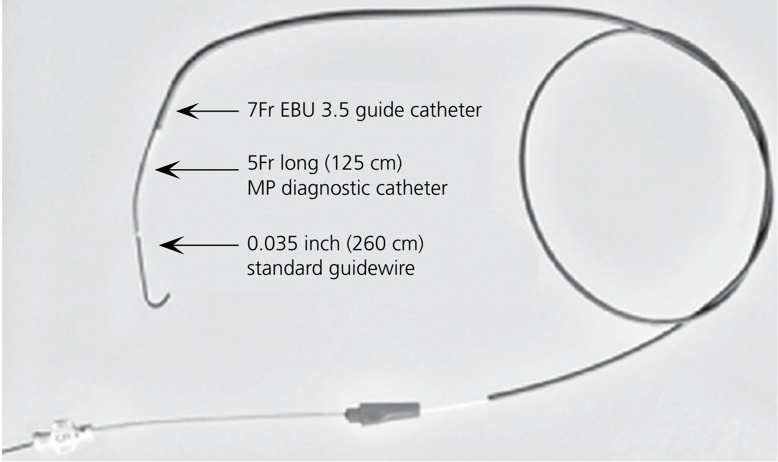

Figure 8.19 In vitro demonstration of modified mother-and-child assembly. Source: Reproduced with permission from [21] / John Wiley & Sons.

(125 cm) diagnostic catheter. The "combo" technique should be restricted to the use of a 7-Fr guide catheter system for a regular RA lumen and relatively simpler vascular anatomy. Both these techniques effectively eliminate "razor effect" to the intima of the arm and chest vasculature and help minimize damage and local pain. The "combo" technique may have an impact on reduction of RA perforation that leads to hematoma as well as RA occlusion.

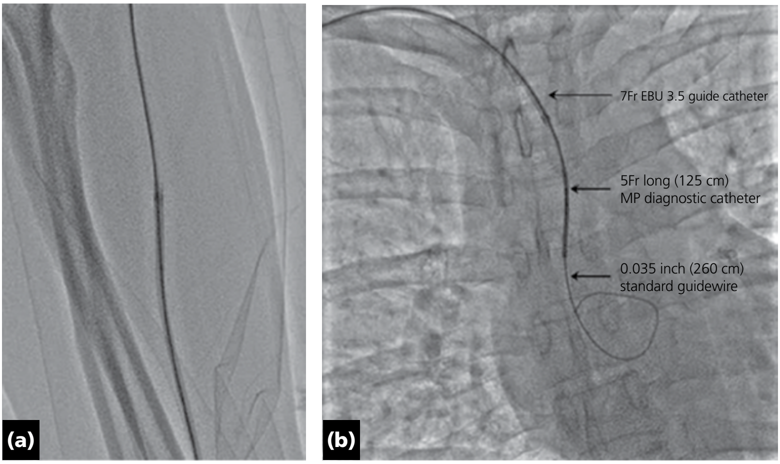

Figure 8.20 (a) A 7-Fr EBU 3.5 guide catheter over a 5-Fr long (125 cm) MP catheter was introduced over a 0.035-inch (260 cm) standard guidewire. (b) The assembly in the ascending aorta.

OTHER PROCEDURES

Right Heart Catheterization

A small number of patients undergoing coronary angiography have indications for right heart catheterization. In keeping with the philosophy of immediate patient mobilization, right heart catheterization can be easily and safely performed from the veins of the elbow. In most cases, the veins are 5-Fr compatible. This allows implantation of a 5-Fr temporary pacemaker if needed. When the access site is the cephalic vein, there are sometimes difficulties navigating the wire or catheter because of the unfavorable angle with the subclavian vein. If the wire or catheter repeatedly enters the coronary sinus, it can be withdrawn and preformed with a large curve that enables entry into the right ventricle and pulmonary artery.

Tips and Tricks

A venogram from the arterial injection A useful trick is to inject a few milliliters of contrast through the sidearm of the sheath prior to right heart catheter insertion. With advancement of the catheter, this small volume of contrast forms a moving "venogram" road-map to delineate the venous anatomy and guide smooth advancement. In most cases, the forearm access provides advantageous angulation to promote catheter exit through the right ventricular outflow tract into the pulmonary artery, thereby making this approach often easier than TFA [22].

Bifurcations

TRA is compatible with most bifurcation techniques and new-generation balloons and stents except for trifurcation PCI, certain cases with standard crush technique, kissing stents, and some dedicated devices when RAs cannot accommodate larger than 6-Fr guides.

Chronic Total Occlusion

Good guide support, which is essential for this subset of PCI, can be achieved with most femoral curves transradially. Other techniques specific for CTO PCI, such as the use of microcatheters, anchor balloon, double or triple wire, and deep intubation, can be easily applied via the TRA. If needed, contralateral injection can be performed by using the left RA or the ipsilateral femoral artery.

COMPLICATIONS

The complication profile of TRI is different from those related to the femoral route, with no life-threatening complications and no need for vascular surgery or blood transfusions. Most radial complications are preventable.

Spasm

RA spasm is the most frequent problem with transradial heart catheterization. It causes patient discomfort and reduces procedure success rate. Risk factors for spasm are patient- and operator-related and include anxiety, age, female gender, improper sheath:lumen ratio, tortuosity, hematoma, and repeated puncture. It is much more frequent at the beginning of the learning curve.

Tips and Tricks

***How to avoid radial spasm** Give the patient adequate sedation. Keep the cardiac catheterization laboratory atmosphere quiet and peaceful. A cheerful attitude may also help. Use appropriate sheath size and, by preference, the hydrophilic sheaths. Use fluoroscopy to see the problem each time resistance is encountered. Give a generous dosage of vasodilators.

***How to reverse radial spasm** Apply a sphygmomanometer cuff to the upper arm and inflate to 40 mmHg above systolic blood pressure to occlude brachial artery flow (Figure 8.21). The cuff should be kept inflated for 5 min, and then briskly release it. Upon resumption of flow, evidenced by plethysmographic signal from a sensor placed on the ipsilateral index finger, gentle traction is applied to the sheath.

Radial Occlusion

This occurs in 3–5% of cases and is asymptomatic as a rule. Fifty percent of radial occlusions spontaneously recanalize over time. Predictive factors for radial occlusion include long duration of catheterization, high sheath:artery ratio, heparin dosage, longer sheath, and prolonged compression times [23].

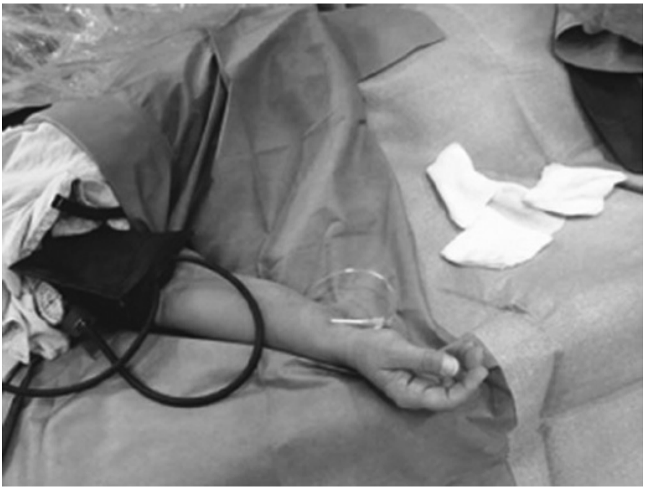

Figure 8.21 A sphygmomanometer cuff is placed at the level of the mid-upper arm and inflated to 40 mmHg above systolic blood pressure. Source: Reproduced with permission from [24] / John Wiley & Sons.

Tips and Tricks

****Patent hemostasis** After putting the bandage pressure on the RA access, release the pressure slowly until a small spurt of blood is seen. This is the ideal pressure to allow a patent antegrade flow while being strong enough to seal the RA access.

Bleeding, Latrogenic Radial Artery Perforation

One of the most common reasons for femoral crossover is iatrogenic perforation or dissection of the RA, which can usually be treated conservatively with a proximal pressure bandage. If undetected, perforation may lead to severe forearm hematoma.

Tips and Tricks

****How to continue the procedure when a perforation has occurred** Insert a long sheath across the perforation or a 4-Fr MP long (130 or 150 cm) catheter and over it a 5- or 6-Fr guide. This maneuver reduces friction, and the 6-Fr guide temporarily seals the dissection/ perforation plane. This is especially helpful when there is accompanying spasm. The maneuver resembles the mother-and-child technique used for increasing support during CTO PCI. It can be used in cases of radial perforation when one wants to finish the procedure transradially, or there are no other available access sites. Perforation is usually caused by the wire. Frequently, there is spasm in the adjacent segments of the RA and it is usually impossible to traverse it with a 6-Fr guide. If the wire is still in place, the operator can insert a 4-Fr long MP (130 or 150 cm). Then, the 6-Fr guide that has been premounted over the 4-Fr MP before introducing the "ensemble" into the 6-Fr sheath is navigated over the 4-Fr MP catheter, thus reducing the risk of further vessel trauma.

If the wire has been withdrawn proximal to the perforation, the operator can use a non-hydrophilic PCI wire and insert over it the MP catheter and so on. Once the guide is in the left or coronary sinus near the ostium of the target vessel, the 4-Fr MP can be withdrawn and PCI can be performed [25] (Figure 8.22).

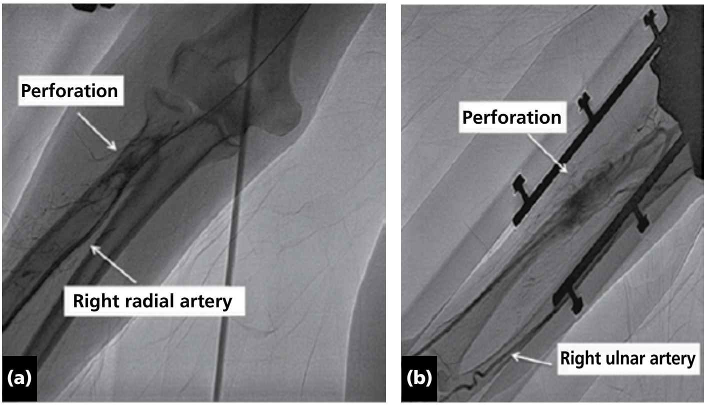

Figure 8.22 (a) An iatrogenic radial artery perforation complicating coronary intervention. Right radial artery, a few millimeters from its origin, shows perforation and intense spasm; the perforation is most likely induced by the tip of the wire and/or the diagnostic catheter and extravasation aggravated by antithrombotic therapy. (b) Spontaneously sealed perforation. At completion of the procedure, the perforation spontaneously closed. The white line in the middle of the right radial artery is the reverberation of the 0.014-inch PTCA wire. Source: Reproduced with permission from [26] / John Wiley & Sons.

GAME PLAN

Iatrogenic RA perforation is a rare but serious complication of PCI via the radial approach that carries a potential risk of acute hand ischemia and its major sequelae. Immediate recognition of this complication and prompt action are necessary including neutralization of heparin, crossing the perforated segment with a wire, and deployment of either a diagnostic or guide catheter across the bleeding source. When the above measures are not successful in stopping the bleeding, external compression by sphygmomanometer cuff may help in sealing the perforation. Despite much literature reporting management of this complication by such simple strategies, not every case can be treated conservatively. If these measures fail, prolonged balloon inflation across the perforated segment may aid in holding bleeding; non-flow-limiting dissection may be left without further intervention. If all other measures fail to stop the bleeding, a coronary polytetrafluoroethylene (PTFE)-covered stent is an effective solution to the potential dreaded complication of compartment syndrome (Figure 8.23).

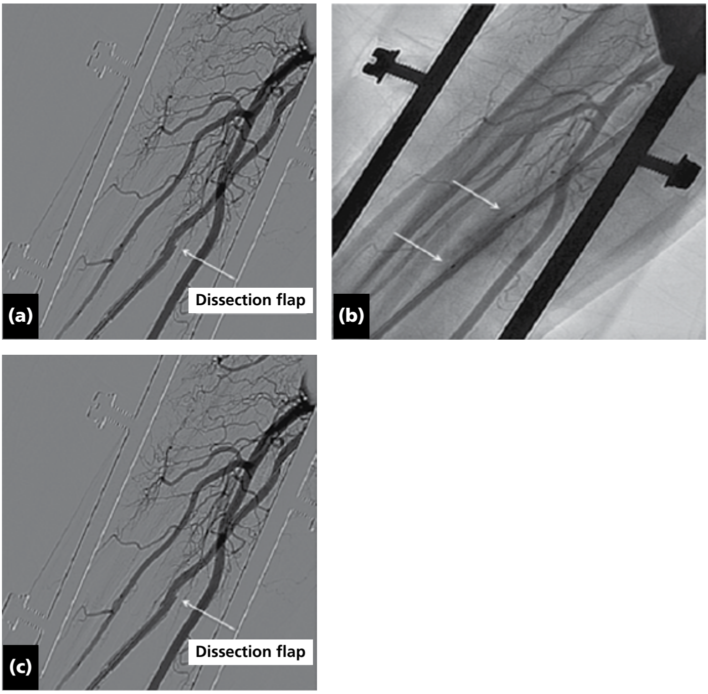

Figure 8.23 (a) Radial perforation induced by guidewire of the sheath. Before coronary angiography, perforation of the right radial artery was noticed. A 0.032-inch hydrophilic Terumo glide wire meticulously crossed the perforated segment, and then coronary angiography was accomplished. (b) Conventional balloon at the perforated radial artery segment. Two arrows point to a 3.0/15-mm conventional semicompliant balloon inflated twice at 6 atm and then at 8 atm. (c) Non-flow-limiting dissection complicated plan-only balloon angioplasty. Final right radial angiogram confirmed sealed perforation but complicated by non-flow-limiting dissection that was left without further intervention. Source: Reproduced with permission from [26] / John Wiley & Sons.

Distant Hematoma

This is associated with bleeding remote from the puncture site. Most distant hematomas are caused by perforation of a small side branch by the wire, especially with concomitant use of glycoprotein (GP) IIb/IIIa blockers. It can be effectively managed with a cuff or elastic bandage applied to the forearm. It is reasonable to lower blood pressure or reverse heparin with protamine when feasible.

Management of Pseudoaneurysm

Pseudoaneurysms (PA) are small as a rule and can usually be treated conservatively by exerting local pressure. The TR Band® was originally developed as a compression device to assist hemostasis of the RA after a transradial procedure. The device has a transparent plate that is positioned over the PA and secured via a Velcro strap. The inflator syringe permits accurate pressure adjustment as air is injected into the side port, which inflates the compression balloon overlying the PA [27].

Hematoma Under Tension

This rare complication may require a surgical drain for a couple of days. **Volar compartment syndrome** is an extremely rare complication for which surgical fasciotomy may be indicated. **Entry site infection/allergy** presents as a delayed skin reaction (2–3 weeks post-catheterization) and is caused by sterile inflammation. It is related to transradial catheterization and the use of a particular brand of hydrophilic sheaths.

Retroperitoneal Bleeding from the Radial Approach

After PCI from the TRI, a patient complained of left leg weakness and numbness in the medial aspect of his thigh and calf and was unable to walk without support. Examination confirmed absent knee reflexes on the left side with weakness of hip flexion, consistent with femoral neuropathy. It was noted that his hemoglobin had fallen to 10.3 g/dL, although he remained hemodynamically stable. A computed tomography (CT) scan of the abdomen showed retroperitoneal bleeding [28].

Tips and Tricks

*****Reduction of knotted coronary catheter in the radial artery** A knot developed because of excessive clockwise rotation of the catheter while trying to intubate the RCA ostium. Significant subclavian tortuosity was possibly instrumental in significant resistance and loss of one-to-one torque, leading to excessive rotation of the catheter and development of a tight knot in the RA region. The first option is to advance a 0.035-in. standard wire across the knot; however, it would not be successful if the knot were too tight. There is always the risk of perforating a catheter and the RA if excessive force is applied. The second option is to fix the catheter in a segment distal to the knot; simple counterclockwise rotation from outside is sufficient to unravel the knot. The third option is to immobilize the distal segment of the catheter by applying manual pressure over the brachial artery in the cubital region while having counterclockwise rotation in the proximal segment. If there is inadequate fixation of the distal segment of the catheter due to fat in the cubital region, this technique would be unsuccessful. The fourth option is to apply the cuff of a sphygmomanometer in the brachial region and raise the cuff pressure to 200 mmHg, which immobilizes the distal segment of the catheter. With this maneuver, the chance of unknotting a twisted catheter is higher [29].

Reduction of knotted coronary catheter in the central circulation Occasionally, excessive manipulation can also result in catheter knotting while the tip is in the central circulation. If the conservative maneuvers outlined in the previous section are unsuccessful, snaring of the tip may be useful. A second access site is obtained, which is either contralateral radial/ulnar or femoral. A snare is advanced to capture and affix the catheter tip. The knot can then be untangled with the use of 0.035-inch guidewire and judicious counter directional torquing, as previously discussed.

Compartment Syndrome in the Forearm

Acute compartment syndrome is described as the clinical situation of an increase in tissue pressure (normal up to 9 mmHg) within a non-expandable space. The forearm contains three intercommunicating compartments: volar, dorsal, and radial. Elevated pressure within the forearm impedes the normal capillary flow and lymphatic drainage. In a vicious circle, it drives progressive tissue edema and increases interstitial pressure, which evolves dramatically into irreversible damage of muscular and nervous structures. Within the forearm, the muscles most prone to ischemic damage are those contained in the deep volar compartment and bordered by the radius, ulnar, and interosseous membranes (flexor digitorum profundus and flexor pollicis longus) [30].

The diagnosis of compartment syndrome in the forearm (CSF) is based on symptoms. Acute pain and swelling are the first to appear, with disturbances in distal sensitivity and distal pallor with preserved radial and ulnar pulses. The “five Ps” (pain, pallor, painful stretching of muscles, paresthesia, and pulselessness) traditionally taught are only a way to remember the existence of CSF, but the diagnosis should be made before all five Ps appear. If there is no relief of pressure, the situation evolves acutely into loss of muscular contraction, typical hand position (supination–volar exposure, wrist flexure, metacarpophalangeal extension, and interphalangeal flexure), dysesthesia and, eventually, loss of macroscopic pulse. In the long term, ischemia of muscles and nerves in the forearm produced in the setting of CSF could result in a range of disabilities, from slight contracture of the first three fingers with a slight loss of sensitivity to complete contracture and disability of the whole hand and wrist (Volkmann’s contracture) [30].

Tips and Tricks

*****How to prevent compartment syndrome in the forearm** First, before the procedure, it is mandatory to check, if possible, in an objective manner, the patency of the hand collateral arteries to ensure proper distal flow and to avoid ischemia within the hand during and after the procedure [30].

Second, during the procedure, good management of radial tortuosities and anatomic variations is needed. The use of hydrophilic wires to overcome tortuosities should be done carefully, with radial angiography in case of difficult wire advancement. At the end of the procedure, if there is severe spasm with the removal of the sheath, anti-spasmolytic therapy should be given and the removal should be done when the spasm has decreased. The hemostatic device should be placed directly onto the point of puncture and should be periodically reviewed until hemostasis has been achieved [30].

Third, proper management of anticoagulants and glycoprotein (GP) IIb/IIIa inhibitors adjusted to the body surface area (BSA) and creatinine clearance during and after the procedure is fundamental to avoid any bleeding complication [30].

Fourth, in the postprocedure period, even after several days, it is necessary to take into account every complaint of the patient about pain or swelling at any point of the arm that was used in the percutaneous procedure and adopt appropriate measures to avoid bleeding and fast increase in pressure in the forearm compartment. A specific protocol was designed and is initiated promptly by nurses in order to prevent this complication [30].

The treatment is to inflate a blood pressure cuff 15 mmHg below the systolic pressure with distal oximetry to ensure proper distal flow [30]. Treatment is performed with fasciostomy or medicinal leech.

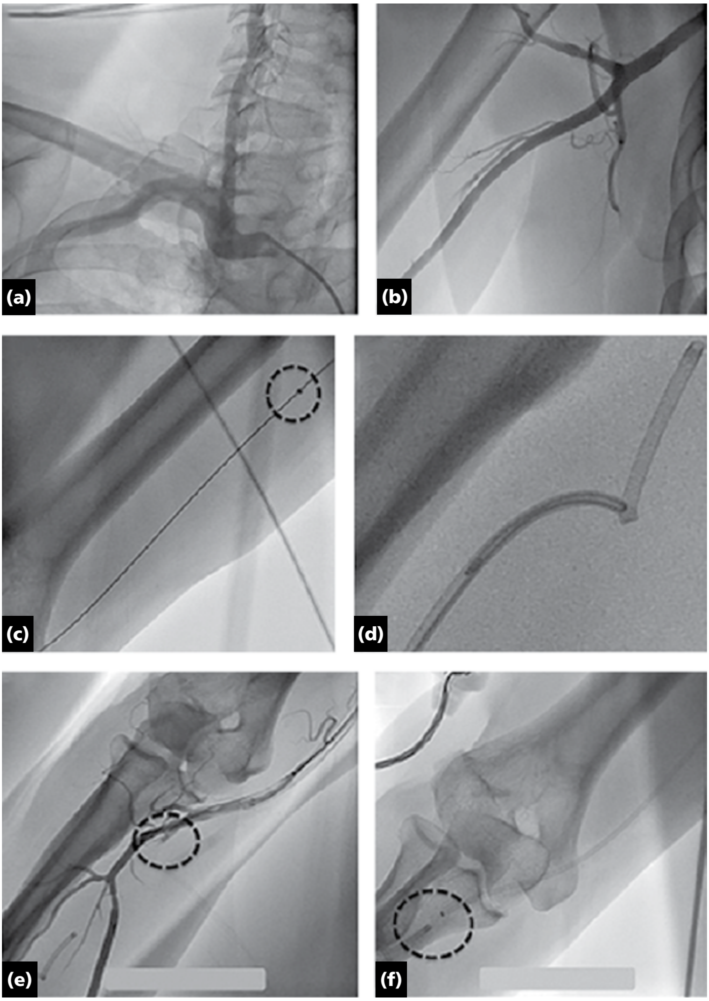

Figure 8.24 (a) Right innominate and subclavian arteriogram. (b) Right axillary and brachial arteriogram. (c) Maximum reach of the distal tip of a transfemoral 100-cm, 7-Fr JR 4 guide catheter (dotted circle) in the upper right brachial artery. (d) Kinked 6-Fr XB guide catheter in right radial artery with unpassable looped 0.035-inch glide wire. (e) Brachial angiogram through partially advanced 7-Fr GuideLiner catheter showing origin of radial artery (dotted circle) with no reflow because of presence of the kinked 6-Fr XB guide catheter further distally. (f) 7-Fr GuideLiner catheter brought into proximity to distal tip of kinked 6-Fr XB guide catheter. Source: Reproduced with permission from [31] / John Wiley & Sons.

Snaring a guide in the brachial artery Unfortunately, the standard 100-cm length, 7-Fr JR 4 guide could only be advanced such that its distal tip was positioned in the right upper brachial artery at maximum reach, which was still some distance from the kinked XB guide catheter lodged in the mid-forearm in this tall-statured subject (Figure 8.24a–d). In anticipating the steps needed to grasp the distal tip of the kinked guide catheter from the TFA using a vascular snare, the only such devices available in our catheterization laboratory were the Atrieve™ Vascular Snare products. Although the included 120-cm length snare would certainly extend beyond the transfemorally placed guide catheter and likely pass through the origin of the RA as it branched off the brachial artery (Figure 8.24e), the proprietary 100-cm length snare delivery catheter would be too short to position the closed snare loops in proximity to the kinked guide catheter in order to enable capture. In fact, the 100-cm length snare delivery catheter would only bring the snare loops to the right upper brachial artery position, given the distal tip location of the 100-cm 7-Fr JR 4 guide catheter, and so it would not be possible to safely negotiate the now-opened snare loops into the smaller RA branch.

RADIATION SAFETY

Increased radiation exposure is a major concern among radialists, especially for the novice. While longer procedural times do occur, especially in the beginning of the learning curve, steps can be taken to mitigate exposure. Radiation scatter occurs from the patient. Therefore, minimize image intensifier–patient distance and maximize source–patient distance, as well as operator–source distance. The last one can be easily accomplished by the addition of a 2-ft extension tubing between the manifold and the guide catheter, thereby allowing the operator to stand at the level of the patient's foot. Shield whenever possible. Leaded caps have become increasingly popular, as the operator's brain is otherwise unprotected. Additional sterile radiation-shielding pads placed on the patient's lap, as well as shielding hand cream, are also potentially beneficial.

In general, use the minimum field size, fluoroscopy frame rate, and magnification required. Remember the acronym ALARA (as low as reasonably achievable). Use "fluoro save" whenever possible, rather than "cine," as it uses less radiation. The source is positioned opposite to the image intensifier; therefore, LAO cranial results in the highest operator exposure, while right anterior oblique (RAO) caudal results in the lowest. A novel ceiling lead suit suspension system, featuring a leaded-glass head shield, provides head-to-foot protection. By eliminating the weight of the lead from the operator's body, this system is able to provide thicker 1-inch lead shielding in addition to great ergonomic and orthopedic relief [32].

The suggested measures are outlined in Box 8.1.

BOX 8.1 CONSIDERATIONS TO REDUCE RADIATION EXPOSURE TO PATIENT AND OPERATOR/STAFF

1. The patient is the source of radiation scatter
2. Use the lowest possible magnification
3. Use the lowest possible fluoroscopic (e.g. 7.5, rather than 15 fps) and cine frame rates
4. "Cone in" or collimate to minimize scatter
5. Place a movable shield near the camera
6. Use undertable apron shields
7. Minimize the camera–patient distance (increasing the distance between the radiation source and patient from 50 to 60 cm reduces the dose rate to the patient by 35%)
8. Minimize camera–image intensifier distance
9. Maximize camera–operator distance
10. Minimize LAO cranial views
11. Maximize RAO caudal views (use for all wire/catheter exchanges)
12. Do not fluoro until the wire reaches the chest, unless resistance is encountered in the arm

(*Continued*)

13. Vary camera angles during the procedure (for patient protection)
14. Remember, when using angulated views, that radiation comes from below the table (image intensifier), opposite to the location of the camera (image intensifier)
15. Pulse fluoroscopy
16. Try to use "fluoro save" in nonobese patients, when documenting balloon inflations, and in noncritical imaging; it uses only 20–25% of the radiation of cine
17. An arm board increases operator distance from radiation source versus femoral approach
18. Increase operator–source distance by adding extension tubing to the manifold. (Remember inverse square law: Exposure varies inversely with distance2. Doubling the distance quarters the exposure)
19. Staff notify operator at 2500 and 5000 mGy.

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CHAPTER 9

Robotic-Assisted Percutaneous Coronary Interventions

Taishi Hirai, Rhian E. Davies, Nguyen Duc Chinh, Thuong Dzung Ho, Ryan D. Madder, and Trung Le

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Robotic-assisted percutaneous coronary intervention (PCI) marked a significant advance in interventional cardiology, with the first human procedure performed in 2008. This innovation was validated by the 2011 Percutaneous Robotically Enhanced Coronary Intervention (PRECISE) study, a landmark multicenter trial demonstrating exceptional technical (98.8%) and clinical (97.6%) success rates. Building on this success, the first-generation Corindus CorPath 200 robotic PCI system received regulatory clearance in 2012, ushering in a new era of precision and control in coronary interventions. The most recent iteration of this system, the CorPath GRX system, was approved in 2016 for robotic control of guidewires, devices (balloons and stents), and guide catheters. In 2018, the achievement of remote in vivo PCI from over 100 miles away was demonstrated. Further, in November 2019, a transcontinental remote PCI simulation within the United States was completed. Although the CorPath system was removed from the market in 2023, this chapter will focus on lessons learned from the CorPath era, including the technical challenges, outcomes, and tips for performing robotic-assisted PCI, and will discuss several emerging endovascular robotic systems.

Advantages of R-PCI

- Enhanced Precision and Stability: Sub-millimeter accuracy reduces human error and improves outcomes for complex lesions [1].
- Improved Operator Safety: Radiation shielding minimizes radiation exposure [2].
- Reduced Physical Strain: Ergonomic design reduces musculoskeletal strain [1].
- Expanded Access to Care: Remote intervention potential addresses geographical disparities [1].

Technical Challenges

Lower pushability and speed of device delivery compared to manual PCI The robotic system limits both the force (pushability) and speed of device delivery, thereby preventing inadvertent deep delivery of devices and potentially avoiding complications. This challenge can be overcome using different interventional techniques to be discussed later in this chapter [3].

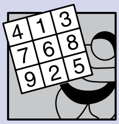
Compatibility with over-the-wire system A major limitation of the CorPath system was its compatibility solely with rapid-exchange balloons/stents. Use of over-the-wire devices, such as microcatheters and rotational atherectomy devices, required conversion to a manual procedure. In complex cases, such as chronic total occlusion (CTO) PCI requiring over-the-wire systems, the CorPath robotic arm would be connected only after manual crossing of the CTO [4].

Compatibility with intracoronary imaging Only the phase array intravascular ultrasound (IVUS) system could be advanced with the CorPath system. The difference in size of this IVUS catheter compared to a balloon catheter could occasionally lead to IVUS catheter damage, especially when the turbo function, which allowed delivery of devices at faster speeds, was used. Rotational IVUS and optical coherence tomography (OCT) catheters were not cleared for delivery using the CorPath robotic cassette. Future improvements in robotic technology are needed to improve compatibility with current IVUS and OCT catheters given the increasing use of intracoronary imaging in modern PCI.

Compatibility with atherectomy The CorPath system could not be used with either rotational or orbital atherectomy, often essential for optimal stent expansion during PCI of severely calcified lesions. However, calcium modification using intravascular lithotripsy is possible using the CorPath system.

Performance of diagnostic coronary angiography The CorPath system was originally designed for use in PCI and was not marketed for performance of diagnostic coronary angiography. This was previously considered to be a limitation, as the number of diagnostic coronary procedures greatly exceeds the number of PCIs performed in the catheterization laboratory annually. Although never intended for this purpose, the CorPath system has since been shown capable of performing diagnostic coronary angiography with high success rates using 5-Fr catheters from both the radial and femoral approaches [5]. This may have important implications given the remarkably low radiation doses to the primary operator when performing procedures robotically.

GAME PLAY



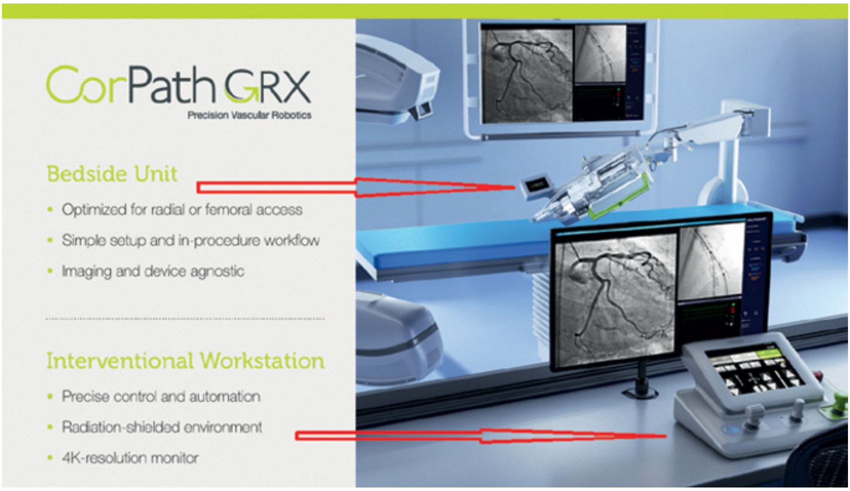
The CorPath system's architecture comprises two integrated components: a bedside unit and an interventional workstation (Figure 9.1). The bedside unit features a robotic arm directly coupled to the procedure table, its cassette (disposable) holding the Y-connector with guiding guidewire and various interventional devices (balloons, stents). This unit houses all the mechanical movements. The interventional workstation, equipped with high-resolution monitors and a control console, enables the primary operator to remotely direct the procedure. Connection is achieved via cable (first-generation systems) or internet (later models), affording precise, remote manipulation of guidewires and catheters for improved procedural success.

BEST PLAYERS

Outcomes for robotic-assisted PCI are similar to those for manual PCI. The goals should be (1) complete revascularization whenever possible, (2) a favorable risk-benefit ratio, (3) adequate debulking for calcification, (4) adequate pre- and postdilation to achieve good minimal lumen area after stenting, (5) preservation of important side branches, and (6) minimizing radiation exposure to the patient, physician, and staff members. Previous studies have shown that similar success rates and safety can be achieved with robotic-assisted PCI when compared to manual PCI [6, 7].

Robotic success, defined as procedural success without manual conversion or procedural complications, is a unique outcome measure for robotic-assisted PCI. The PRECISE study reported a high technical success rate of over 96% in relatively simple lesions [6]. The Complex Robotically Assisted Percutaneous Coronary Intervention (CORA-PCI) study assessed this outcome in more complex lesions with calcification or longer lesions. Among the cases, 82% were completed robotically and 11% required partial manual assistance, with a manual conversion rate of 7.4% [8]. Not surprisingly, the manual conversion rate increases as the lesion complexity increases [9]. The robotic completion rate can be increased by appropriate troubleshooting using some of the tips discussed in this chapter.

R-PCI training incorporates a structured curriculum blending theoretical knowledge with hands-on experience. Initial training at specialized centers (like the Corindus Robotic Academy) utilizes ex vivo simulators and animal models to develop proficiency in guide catheter engagement, wire navigation, and complication management. Clinical training progresses from simpler (A/B1) to more complex cases, requiring at least three supervised procedures before independent practice. Competency is typically achieved after approximately 50 procedures, as demonstrated by a manual conversion rate under 10% and robotic procedure times within 15% of manual benchmarks after 10–15 cases (Patel). Initial procedures are generally longer, with significant improvement observed as experience increases [7, 10, 11].



CorPath GRX

Precision Vascular Robotics

Bedside Unit

- Optimized for radial or femoral access
- Simple setup and in-procedure workflow
- Imaging and device agnostic

Interventional Workstation

- Precise control and automation
- Radiation-shielded environment
- 4K-resolution monitor

Figure 9.1 CorPath GRS system. Source: Reproduced with permission from Corindus / Siemens Healthcare Private Limited.

Connecting the robotic drive to the guiding catheter The CorPath robotic system consists of a bedside robotic drive onto which a sterile disposable cassette (Figure 9.2) is attached for each case. When performing robotic PCI, arterial access and guide catheter seating are performed manually. A "robotic cogwheel" is attached between the Y-connector and the guide catheter to facilitate robotic guide catheter torquing. The guide catheter is then set into position in the disposal cassette. A plastic cover that extends to the radial sheath prevents kinking of the guide catheter during advancement and withdrawal by the robotic drive.

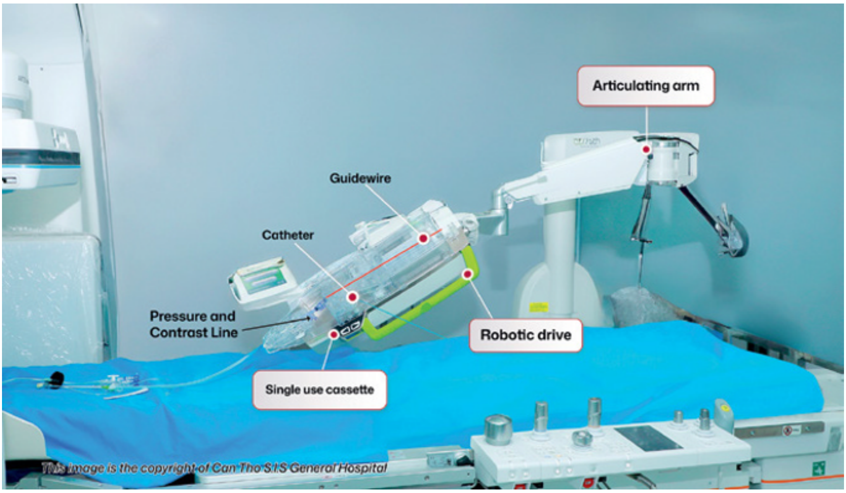

Articulating arm
Guidewire
Catheter
Pressure and Contrast Line
Robotic drive
Single use cassette
This image is the copyright of Can Tho S.I.S General Hospital

Figure 9.2 Sterile Disposable Cassette.

Advancement of the balloon/stents and guidewire An 0.014-inch coronary guidewire is manually inserted into the guide catheter and then placed into the center of the cassette (Figure 9.2). A balloon or stent catheter is advanced over the guidewire into the guide catheter and then placed into the balloon port of the cassette (Figure 9.2).

Control by the primary operator using the robotic arm The CorPath GRX system employs three joysticks for (a) balloon and stent control, (b) guidewire control, and (c) guide catheter control (Figure 9.3). The joystick for the device can be advanced forward and backward. Use of the turbo button during device advancement increases the delivery speed by four times. The guide catheter, guidewire, and balloon/stent catheters can also be manipulated using a series of touchscreen buttons.

Tips and Tricks

Failure to cross a lesion The best maneuver for advancing a balloon across a tight lesion is to increase guide catheter support [3]. It is important to select a guide catheter with appropriate support. Consider using a larger guide catheter (7 Fr) or a more aggressive shape and/or length (AR or AL guides for the right coronary artery, longer EBU guides) when there is anticipated difficulty with delivering the balloon or devices (due to tortuosity or calcification). The 7-Fr guide catheters were compatible with the CorPath system, and it will be important for future robotic systems to be similarly compatible with larger guide catheters.

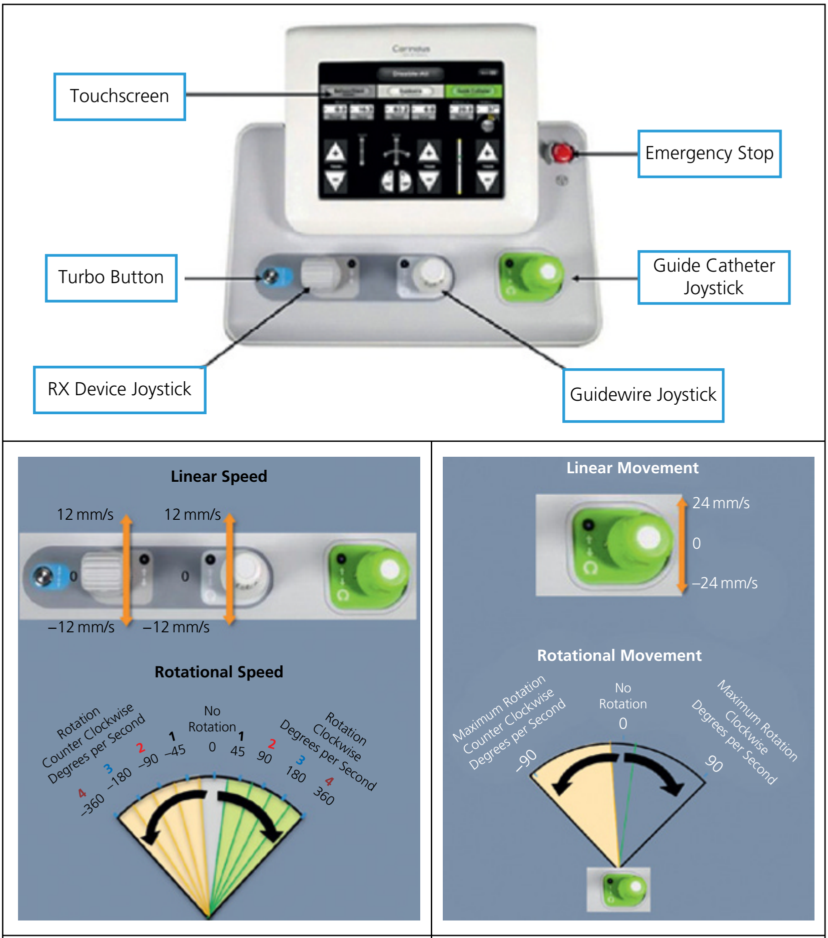
Deep seating of the guide catheter This can be performed by simultaneously advancing the guide catheter robotically while retracting either the guidewire or balloon/stent catheter. Deep seating of the guide catheter can also be accomplished by retracting a balloon while inflated in the target vessel.

Increasing the speed of delivery (Using the turbo button) The turbo feature was not developed for use in the coronary arteries, but similar to the effect of the operator wiggling the balloon or stent when advancing manually, this turbo technique can sometimes overcome difficulties encountered during device delivery.

Advancement of guide-extension catheter Use of guide-extension catheters with the CorPath system has been described. Guide-extension catheters can be advanced by the bedside assistant operator. Typically, the “inch-worming technique” is used by advancing the balloon robotically, inflating the balloon, and then advancing the guide catheter manually [3].

Use of buddy guidewire Advancing a second guidewire can be helpful in straightening the vessel. This can sometimes improve lesion crossing [3]. The CorPath system was capable of robotically manipulating only one guidewire at a time, but it had a position in the cassette to park a second guidewire when using any two-wire technique.

Transitioning out the workhorse wire for a wiggle wire (Abbott cardiovascular, MN, USA) The workhorse wire can be exchanged by the assistant at the tabletop using a microcatheter, which can be advanced over the workhorse wire. The workhorse wire is then removed and exchanged for the Wiggle wire. The microcatheter can then be removed with minimal difficulty, as the wiggles on the Wiggle wire will often hold it in the current location. Alternatively, the microcatheter can be removed using a trapping technique.


Touchscreen
Emergency Stop
Turbo Button
Guide Catheter Joystick
RX Device Joystick
Guidewire Joystick
Linear Speed
12 mm/s
12 mm/s
0
0
−12 mm/s
−12 mm/s
Rotational Speed
Rotation Counter Clockwise Degrees per Second
No Rotation
Rotation Clockwise Degrees per Second
4 -360
3 −180
2 -90
1 −45
0
1 45
2 90
3 180
4 360
Linear Movement
24 mm/s
0
−24 mm/s
Rotational Movement
Maximum Rotation Counter Clockwise Degrees per Second
-90
No Rotation
0
Maximum Rotation Clockwise Degrees per Second
90

Guidewire and Device Joystick Control
Linear and rotational movement
Linear Movement: RX Device and Guidewire
- Advances or retracts faster as the user moves the joystick farther from the neutral position — Speed increases incrementally up to 12 mm/s

Rotation: Guidewire
- The speed of rotation increases incrementally as the guidewire joystick is rotated
- 4 speeds available, clockwise and counter clockwise
  - Speed 1 = 45° per second
  - Speed 2 = 90° per second
  - Speed 3 = 180° per second
  - Speed 4 = 360° per second (maximum)

Guide Catheter Joystick Control
Linear and rotational movement
Linear Movement
- Advance/retract speed increases incrementally up to 24 mm/s as the joystick control moves further away from the neutral position

Rotation
- Can rotate clockwise or counter clockwise with up to 90° rotation per second as joystick moves further from the neutral position

Figure 9.3 Control console.

Table 9.1 Functional performance of CorPathGRS system

FUNCTIONAL PERFORMANCE	
Guide Catheter Linear Velocity	0 to 24 mm/s
Guide Catheter Rotational Velocity	0 to 90°/s
Guide Catheter Linear Position Error	≤ ±2.5 mm
Guidewire Linear Velocity	Normal Mode: 0 to 12 mm/s Turbo Mode: 0 to 60 mm/s
Guidewire Rotational Velocity	Normal Mode: 4 speeds: 45°, 90°, 180°, 360°/s
RX Device Linear Velocity	Normal Mode: 0 to 12 mm/s Turbo Mode: 0 to 60 mm/s
Guidewire Linear Position Accuracy	±0.1 mm using touch-screen keys
RX Device Linear Position Accuracy	±0.1 mm using touch-screen keys
Rotational Position Accuracy, of Guidewire	±3° using touch-screen keys
Linear Measurement Error, Guidewire	± (10% + 0.1) mm
Linear Measurement Error, RX Device	± (10% + 0.1) mm

Using technIQ Conventional robotic coronary interventions use joysticks to control axial and rotational forces on intracoronary devices but lack control over specific wiring techniques. The CorPath GRX system uses AI-powered "TechnIQ" to overcome this, adding pre-programmed maneuvers (spin, wiggle, and controlled rotation) for 0.014 inch and 0.018 inch wires and device manipulations (dottering and constant speed) for rapid-exchange devices (balloons, stents, and imaging catheters).

Three distinct AI-driven "TechnIQ" wiring maneuvers are available on the CorPath GRX system. The spin technique executes a programmed sequence of three 360° clockwise and three 360° counterclockwise rotations during wire advancement, optimizing navigation in vessels with larger lumens and significant tortuosity. The Wiggle technique employs rapid, low-amplitude alternating rotations to enhance negotiation of tight stenoses within smaller vessels. Finally, the rotate-on-retract feature automatically applies a 270° rotation as the wire is retracted, thereby redirecting the wire tip away from side branches and back toward the target distal segment.

The dotter technique applies a rapid alternating "back and forth" movement to the intracoronary device as it is advanced. This replicates a common technique applied by operators to facilitate crossing of difficult lesions, tight stenosis, calcific segments, or stent struts.

The different TechnIQ movements can be simultaneously combined with the joystick and touch-screen controls, and additionally, the operator can easily and instantly switch between different TechnIQ manipulations in order to select the most appropriate wiring and device strategy to tackle the intracoronary challenge. A key advantage of these artificial intelligence-derived movements is their impact on an operator's learning curve and initial experience with R-PCI. Experienced operators can replicate common techniques and movements using the robotic platform, while early-career interventional cardiologists can learn to safely and effectively wire vessels and lesions during R-PCI [12].

How to measure lesion length Target lesion length can be accurately measured using the CorPath robotic system by positioning the distal marker of a stent or balloon 5–10 mm beyond the desired distal landing zone (Figure 9.4). The device is then retracted so that the distal marker is at the desired distal landing zone, thereby removing any slack from the system that

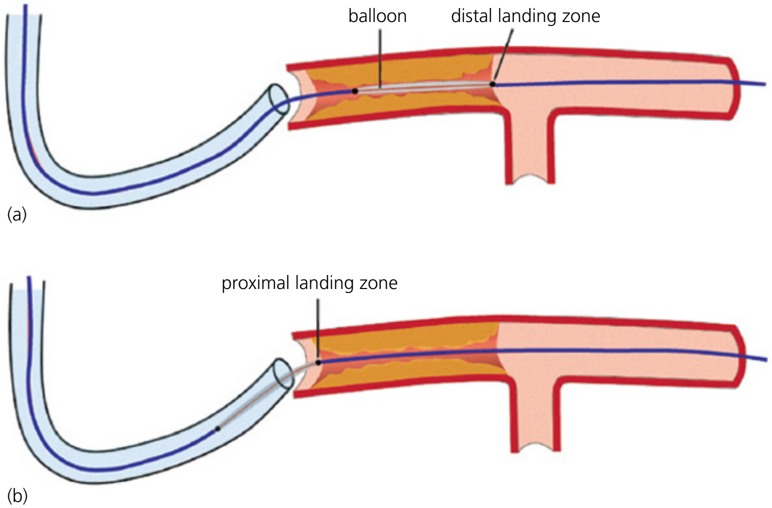


Figure 9.4 Robotic lesion measurements. a. Positioning the distal marker of a stent or balloon at the desired distal landing zone. b. The distal marker is located at the desired proximal landing zone, and the lesion length will be displayed on the monitor.

could lead to overestimating the true lesion length. The operator then resets the distance measurement by touching the "reset button" on the touch screen. The stent or balloon is then withdrawn robotically so that the distal marker is located at the desired proximal landing zone (Figure 9.4); the lesion length will then be displayed on the touch screen. It should be noted that the accuracy of the software depends on 1:1 joystick input to movement responsiveness of the device, which is not always the case. If the device is stuck, the program will still count and render an inaccurate measurement. Prior data have also suggested that R-PCI lowers the incidence of longitudinal geographic miss compared to manual PCI [13]. This is likely related to a combination of improved measurement accuracy with the robotic software, improved visualization given closer screen proximity for the operator, and finally the controlled pinning of the device during inflation and deployment by the robot gears.

Confronting the Challenges

The guide catheter becomes unseated during the PCI If the guidewire is still in the vessel, the best maneuver in this situation is to advance the balloon into the vessel (forward motion of joystick [a]), inflate the balloon, and then withdraw it (backward motion of joystick [a]). The guide catheter can also be simultaneously advanced at this time (forward motion of joystick [c] and backward motion of joystick [a]). The guide catheter may also be advanced or torqued back into the vessel using the guide catheter joystick or touchscreen buttons.

Treatment of bifurcation lesion requiring a two-stent strategy Since the current robotic system can only advance one guidewire and one balloon at a time, when two stent strategies are required, constant switching of the guidewire advanced by the robotic control and the guidewire placed at the resting port will be needed. When kissing balloon inflation is performed, one balloon is advanced robotically and the second balloon is advanced manually with simultaneous kissing balloon inflation. The assisting operator at tableside must be cautious to not create "wire-wrap," which can occur when alternating wires from primary to secondary seats.

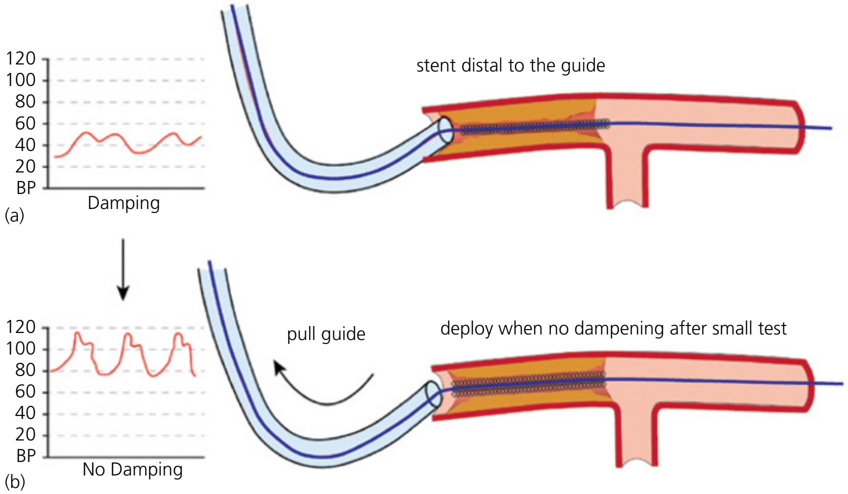

120
100
80
60
40
20
BP
Damping
(a)
stent distal to the guide
120
100
80
60
40
20
BP
No Damping
(b)
pull guide
deploy when no dampening after small test

Figure 9.5 Step-by-step treatment of ostial lesion. a. The stent can be positioned right beyond the edge of the guide catheter with the guide catheter deep-seated in the vessel. b. The guide catheter is withdrawn robotically using the joystick, which will withdraw the stent and guidewire as a unit.

Treatment of ostial lesion When treating an ostial lesion, the CorPath system has the advantage of taking away the device and guide catheter interaction. The stent can be positioned right beyond the edge of the guide catheter with the guide catheter deep-seated in the vessel (Figure 9.2a). Typically there is pressure damping. Then the guide catheter is withdrawn robotically using joystick [c], which will withdraw the stent and guidewire as a unit, keeping the relative distance of the stent and guide catheter tip the same. This will allow for precise positioning once the guide catheter has a good pressure waveform (Figure 9.5).

Discriminating Differences

Several novel robotic systems are either in clinical use or under development for the performance of endovascular interventions. Following the exit of the CorPath system from the market, these emerging systems, three of which are described below, have the potential to form the foundation of the second era of endovascular robotic interventions.

R-one The R-One robotic system (Robocath), currently in clinical use in Europe but not yet available in the United States, has functionality similar to the original CorPath 200 system in that it can robotically navigate a guidewire and balloon/stent catheter but not a guide catheter. The R-One system was recently shown to perform PCI with high technical and procedural success rates and was associated with low radiation doses to the primary operator.

Liberty The Liberty robotic system (Microbot Medical) has been designed as a miniaturized, single-use, disposable robot for the performance of endovascular procedures. Controlled by a Bluetooth-enabled handheld controller, the Liberty robotic system is compatible with over-the-wire systems. A single preclinical study was recently performed to assess the technical capabilities of the Liberty robotic system in the performance of PCI. In this study, the Liberty robot was able to advance, retract, and torque coronary devices in a manner necessary to perform PCI without the need for manual conversion. Furthermore, the Liberty robot delivered devices as efficiently as a manual control group but faster than a control group using the CorPath GRX. In fact, a 60% reduction in wiring time was observed with the Liberty system compared to CorPath. Owing to its disposable design, the Liberty system will not likely require a large capital purchase by a healthcare system in order to establish a robotics program. The Liberty robotic system is not yet available for clinical use in humans.

Nanoflex The Nanoflex robotic system (Nanoflex), currently under development for the performance of endovascular robotic procedures, differs from other systems in that it projects a magnetic field onto the patient and steers intravascular devices by robotically manipulating the direction of the magnetic field. The Nanoflex robotic system is not yet available for clinical use in humans.

CONCLUSION

Although the first phase of robotic-assisted PCI has ended with the removal of the CorPath system from the market, we believe robotic technology will play an important role in further improving the treatment offered to our patients. We have summarized the challenges and solutions learned from the CorPath era in this chapter to share with future robotic operators.

DISCLOSURES

Dr. Hirai received speaking honoraria from Abiomed and Asahi Intecc. He received an institutional research grant from Abiomed and Asahi Intecc. The remaining authors have nothing to disclose. Dr. Davies reports speaking honoraria from Abiomed, Asahi Intec, Boston Sci, Medtronic, Shockwave, and Teleflex. She also serves on advisory boards for Abiomed, Avinger, Boston Sci, Medtronic, and Rampart. Dr. Madder has received speaker honoraria from Abbott Vascular, Corindus, and Infraredx; has served as a consultant to Abbott Vascular, Angiowave Imaging, Corindus, Infraredx, Nanoflex Robotics, RapidAI, and Spectrawave; has received research support from Angiowave Imaging, Corindus, Infraredx, and Nanoflex Robotics; and serves on the advisory boards of Medtronic and Spectrawave.

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CHAPTER 10

Left Main Percutaneous Coronary Intervention

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⧖, <10 min extra; ⧖⧖, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Significant (>50%) left main (LM) coronary artery (LMCA) disease is observed in approximately 4–7% of patients who undergo coronary angiography [1]. With improvements in stent technology and adjunctive pharmacotherapy, percutaneous coronary intervention (PCI) has become a feasible, safe, and efficacious alternative to coronary artery bypass graft (CABG) in selected patients with unprotected LMCA (ULMCA) disease. Over the last 15 years, drug-eluting stents (DES) have been the preferred stent type given the lower rates of restenosis and the need for repeat revascularization [2]. In many countries around the world, ULMCA PCI with a DES is routinely performed in more diverse patient populations. Patients with preserved left ventricular (LV) function who undergo elective PCI, as well as patients with low SYNTAX (Synergy between PCI with Taxus and Cardiac Surgery) score (<23), are generally good candidates for ULMCA PCI [3]. Favorable anatomical locations for successful PCI include ostial and mid-shaft lesions. ULMCA PCI is also a viable alternative to CABG in patients who are poor surgical candidates due to severe LV systolic dysfunction, significant comorbidities such as severe chronic obstructive pulmonary disease and severe cerebrovascular disease, or limited life expectancy, or according to patient preference. Patients who are not ideal for ULMCA PCI are those with high anatomic complexity (i.e. SYNTAX scores [>32]) [4].

GAME PLAN

Identification of severe ULMCA disease sometimes can be challenging with coronary angiography due to uncertainty and interobserver variability. Determination of the severity of LMCA stenosis can be difficult, especially when the length of the LMCA is short or in the presence of calcification, overlapping vessels obscuring the degree of stenosis, Mach band effect, and inadequate visualization of the ostial LMCA lesion. Mach band effect is an optical illusion where the retina enhances edges, causing the edge of a darker object adjacent to a lighter object to appear darker, and vice versa, creating false shadows or bands of brightness. Thus, in the contemporary PCI practice, adjunctive tools such as intravascular ultrasound (IVUS) and fractional flow reserve (FFR) that assess anatomy and hemodynamic significance are invaluable for the diagnosis of significant ULMCA disease.

In 2024, the European Society of Cardiology (ESC) released influential guidelines for the management of chronic coronary syndromes, which state that "intracoronary imaging guidance by intravascular ultrasound (IVUS) or optical coherence tomography (OCT) is recommended for performing percutaneous coronary intervention (PCI) on anatomically complex lesions, particularly those involving the LM stem (LMS), true bifurcations, and long lesions." This guidance is classified as Class I with a Level of Evidence A, underscoring its significance in clinical practice [5].

Similarly, the 2025 American College of Cardiology guidelines for the management of acute coronary syndromes have reiterated the critical role of intravascular imaging (IVUS and optical coherence tomography [OCT]) in guiding PCI procedures for complex lesions in the LM artery. This recommendation is also categorized as Class I with a Level of Evidence A, highlighting its importance in reducing the incidence of ischemic events [6].

Currently, the application of IVUS and OCT guidance for PCI in the LM artery is recognized as essential in both acute and chronic clinical settings, supported by experts from both sides of the Atlantic. These advanced technologies are integral to accurately assessing lesion severity, ensuring precise stent placement, and optimizing patient outcomes. IVUS offers a detailed assessment of the vessel wall, facilitating the evaluation of plaque burden, calcification extent, and lesion measurements. Post-deployment, IVUS is crucial for assessing minimum stent area (MSA), identifying malapposition or under expansion, and detecting edge disease or dissections.

OCT complements IVUS with high-resolution imaging that allows for precise evaluation of calcium thickness, lipid presence, thrombus formation, and plaque ruptures, especially in acute coronary syndrome. It is also effective in examining stent apposition and measuring neointimal thickness. While OCT has limitations regarding imaging depth and requires contrast injection, these can be managed in complex scenarios [6].

Both IVUS and OCT play fundamental roles in determining lesion preparation needs, selecting appropriate stent sizes, confirming optimal expansion, and reducing geographical errors. Furthermore, they help identify complications and clarify causes of stent failure. The integration of these advanced imaging techniques is vital for improving patient outcomes in coronary interventions [6].

Fractional Flow Reserve for Left Main

FFR is a physiological parameter that indicates the severity of epicardial stenosis as well as the corresponding myocardial perfusion. This measure reflects the extent to which a coronary stenosis impacts the maximal blood flow to the myocardium supplied by the affected artery. Numerous studies have demonstrated that in cases of angiographically intermediate unprotected LM (ULM) lesions, revascularization is safely deferred when the FFR value is ≥0.75. The mortality rates observed in these patients are comparable to those in individuals with significant ULM stenosis who undergo CABG, with follow-up assessments spanning up to five years. It is imperative to adhere to specific principles when conducting FFR assessments in LMS lesions to mitigate the risk of false-positive or false-negative results. Should the FFR results be inconclusive, the operator may need to incorporate IVUS imaging to enhance interpretability.

When assessing the clinical significance of LMS lesions through FFR, it is crucial to apply specific principles to avoid both false-positive and false-negative outcomes. The integration of intravascular imaging techniques, such as IVUS, may be required in specific situations to enhance assessment accuracy.

In instances where a single LM lesion is located at the ostium or shaft, with a significant distance separating the bifurcation from the distal portion of the lesion, it is essential to position the pressure wire appropriately to ensure accurate results. For a single LM lesion situated at the bifurcation, it is vital to place the pressure wire in both branches to circumvent false-negative results, specifically when the FFR is greater than 0.80. Of all the coronary segments, the LM exhibits the greatest angiographic variability.

Figure 10.1 outlines the fundamental principles for conducting pressure wire assessments in LMS disease, emphasizing the critical positioning of the pressure wire transducer. It is necessary to decannulate the guide catheter from the LM ostium during pressure wire evaluation to prevent signal damping. Additional intravascular imaging techniques, such as IVUS, may be warranted under particular circumstances.

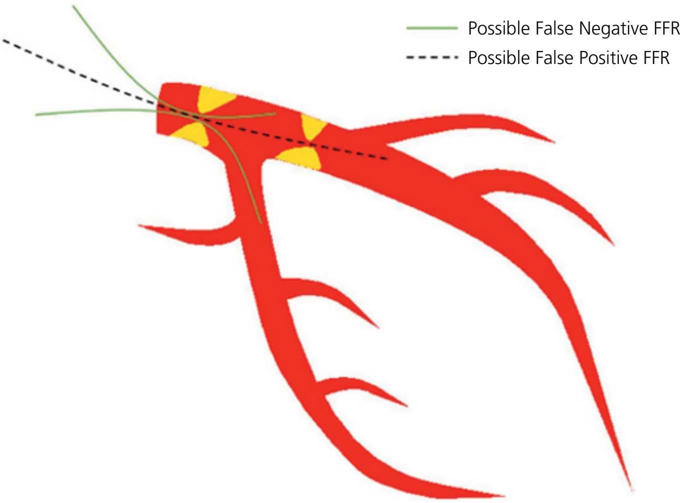

Figure 10.1 Fundamental principles for conducting pressure wire assessments in left main (LM) disease. It is necessary to decannulate the guide catheter from the LM ostium during pressure wire evaluation.

BEST PLAYER

Intravascular Ultrasound for Left Main

IVUS is superior to quantitative coronary angiography (QCA) for assessing reference diameter, minimum lumen diameter (MLD), and diameter stenosis of the LMS. IVUS provides high tissue penetration, enabling visualization of the entire vessel wall, which allows for the assessment of vessel remodeling and total atheroma burden.

In angiographically ambiguous LMS lesions, an IVUS-derived minimum lumen area (MLA) cutoff of 5.9 mm^2 has been associated with a FFR of 0.75. Given the discrepancies in the best IVUS MLA cutoff that correlates with FFR, performing FFR or noninvasive stress testing is suggested if the IVUS-derived MLA value is $\geq$6.0 mm^2.

The criteria for minimal stent area (MSA) post-PCI ULMCA are approximately 8 mm^2, 7 mm^2, 6 mm^2, and 5 mm^2 for the proximal LMS, polygon of confluence, ostial left anterior descending (LAD) artery, and ostial left circumflex (LCX) artery, respectively. These cutoff values are associated with reduced in-stent restenosis (ISR) at 9 months and freedom from major adverse cardiac events (MACEs) at 2 years [7].

LCX ostial measurements cannot be reliably assessed using IVUS pullback from the LAD to the LMS. It is recommended to evaluate the LAD and LCX ostia by performing separate pullbacks in their respective vessels.

Tips and Tricks

****Safe and successful intravascular ultrasound** When performing IVUS in the LM, it is important to use a JL 4 guide to prevent deep intubation. Coaxial positioning of the guide tip should be ensured to achieve accurate visualization of all vessel wall layers, particularly given the large diameter of the LM. For optimal imaging of the LM ostium, decannulation of the guide is often required. An automatic pullback speed of 0.5 mm/s is typically used; however, a faster rate of 1.0 mm/s may be necessary in very long LM segments to reduce procedural duration and minimize ischemic risk. In cases involving tight lesions, the IVUS probe may temporarily occlude the LM, potentially leading to ischemia or hemodynamic instability; predilatation using a small-diameter balloon may help prevent this. Finally, due to the size of the LM, the imaging depth should be increased to the maximum before initiating IVUS.

For LMS bifurcation analyses, ensure that a coronary wire is passed through both the LAD and LCX. This helps visualize the carina/ostia (by reducing the bifurcation angle) as it would appear after implantation with a metallic stent. The coronary wires can also serve as reference points for analyzing pullbacks. Direct LCX pullback is recommended for evaluating LCX ostial measurements, as measurements taken obliquely from the LAD to LMS using IVUS pullback are only moderately reliable.

Optical Coherence Tomography for Left Main

The high resolution of OCT offers significant value in evaluating stent sizing – both diameter and length – as well as lesion complexity, calcification, stent apposition, and the arterial response to DES. However, the application of OCT guidance in the LM artery is limited by the shallow tissue penetration of OCT light, which hinders accurate measurement of media-to-media distance required for precise stent sizing. Furthermore, visualizing the aorto-ostial segment with OCT remains technically challenging, and published success rates are still awaited.

BEST PLAYERS

Optimal Optical Coherence Tomography for Left Main

To achieve complete visualization of the LM ostium, it is essential to position the catheter tip at a sufficient distance from the coronary ostium. This placement enables optimal imaging with the OCT wire during pullback while maintaining adequate proximity for contrast injection to ensure blood clearance. Although this approach may result in some contrast overflow into the aortic cusp, it is not typically problematic, provided that contrast delivery into the LM is sufficient to displace blood. Despite the technical demands of this technique, it can be reliably executed with operator experience, and favorable success rates have been reported.

As with IVUS, separate pullbacks of the LAD and LCX arteries are recommended. This strategy enhances visualization and allows for more accurate assessment of geometric parameters such as MLD, MLA, and mean stent area (MSA), as previously described.

Due to its high resolution, OCT is particularly useful for evaluating stent dimensions (diameter and length), lesion complexity, calcification, stent apposition, and the arterial wall response to DES. However, OCT guidance in the LM is constrained by its limited tissue penetration, which prevents accurate measurement of media-to-media distance and may affect stent sizing decisions (Box 10.1).

BOX 10.1 PREFERENCE OF TECHNIQUES ACCORDING TO ANATOMY

1. A T-stent, modified T-stent, or TAP (T-stenting with small protrusion) technique may be preferred with a near right-angled (75–90^{0}%) take-off of the LCX
2. A culotte or mini-crush (or double-kissing [DK] crush) technique may be preferred when a shallower LCX angle is present
3. The culotte technique is best suited for a Y bifurcation with matched LAD/LCX diameter
4. The mini-crush or DK crush technique is best suited when LAD and LCX diameters are mismatched
5. The V-stent technique may be preferred with Medina 0,1,1 or true LM equivalent disease
6. The simultaneous kissing stent technique is generally avoided because of the creation of a new metal carina, with anecdotal reports of high complication rates. However, this approach may be useful in an unstable patient with severe bifurcation disease and a short LMCA
7. All two-stent techniques should be completed with final kissing balloon inflation

STENTING TECHNIQUES

Optimizing PCI outcomes, including verifying stent expansion and apposition, is crucial given the large territory of viable myocardium that the LMCA supplies. ULMCA PCI should be reserved for selected patients and performed in high-volume centers by experienced operators. The stenting strategy for ULMCA PCI is generally determined by the location of disease. Ostial and mid-shaft lesions are relatively uncomplicated, whereas distal bifurcation lesions are more challenging and associated with higher rates of restenosis [3]. The reference vessel diameter (RVD) of most LMCA is 4 mm. The options are to either implant a 3.5-mm diameter stent and post-dilate with a 4-mm noncompliant balloon or implant a 4-mm diameter stent. IVUS should be performed routinely after stenting to optimize results [6].

Ostial and Mid-shaft Lesions

PCI of LMCA lesions involving the ostium and mid-shaft is usually uncomplicated and is associated with excellent acute and long-term outcomes. Predilatation is helpful to determine the ability to fully dilate the lesion and for sizing the vessel, especially in cases of very severely stenotic or calcified lesions. A short ULMCA shaft may require stenting across the LCX and extending the stent into the LAD. Short stents (<10 mm) should be avoided given potential risk of stent dislodgment from the ostium of the LM during guide manipulation and post-dilatation. A 6-Fr guide usually via the transradial approach is sufficient for nearly all cases for ostial or mid-shaft lesions.

Tips and Tricks

****Ostial LM stenting** The ideal angiographic projection for stent placement is commonly the left anterior oblique (LAO) cranial or anterior–posterior (AP) projection (Figure 10.2a). The stent should be positioned proximal to the inferior border and distal to the superior border. Positioning of the stent proximal to the superior border may prevent reengagement of the guide into the LMCA. Positioning of the stent distal to the inferior border of the LMCA can lead to inadequate coverage of the ostium. IVUS should be used to ensure adequate coverage of the ostium. Prior to stent deployment, the guide should be disengaged in order to prevent stent deployment inside the guide. After stent deployment, a noncompliant balloon is frequently used to post-dilate the lesion and flare the proximal portion of the stent (Figure 10.2b). A guide with side holes is not usually recommended because of inadequate opacification of the LMCA, except in cases with pressure damping during the PCI.

****Mid-shaft LM stenting** Foreshortening of the LMCA length can occur in the cranial projections. The caudal projections, particularly the right anterior oblique (RAO) and AP, allow

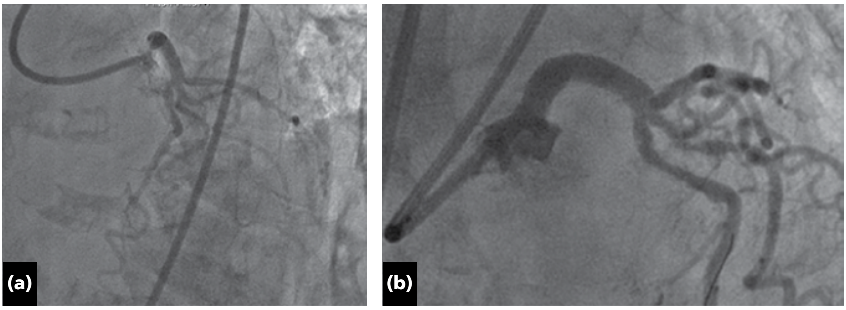

Figure 10.2 (a) Coronary angiography in the left anterior oblique (LAO) cranial projection reveals severe ostial stenosis of the left main. (b) Final angiography after atherectomy and stenting of the ostial left main artery with a 5-mm bare metal stent.

for optimal visualization. The LAO caudal projection is useful to determine the distal landing zone as the origin of the distal bifurcation is often well visualized.

Distal Bifurcation Lesions

Distal bifurcation involvement is common in patients with LMCA stenosis, occurring in approximately 70% of cases. This anatomical pattern increases the complexity of PCI and is associated with higher restenosis rates compared to PCI involving ostial or mid-shaft LMCA lesions. Although no standardized algorithm exists for managing distal bifurcation disease, a provisional single-stent strategy is generally preferred over an upfront two-stent approach when feasible.

The decision between single- and two-stent strategies depends on multiple factors, including the significance of the ostial LCX lesion, lesion length, dominance of the coronary system, and vessel diameter. In general, a one-stent approach is favored when the LCX lesion is nonsignificant (<50%), shorter than 10 mm, occurs in a non-left dominant system, or when the LCX diameter is <2 mm. Conversely, an upfront two-stent strategy is recommended for patients with complex or diffuse LCX disease. As with other bifurcation lesions, provisional stenting is associated with more favorable long-term outcomes compared to routine use of a two-stent technique [8].

Stenting Across Ostium of LCX (Crossover Technique)

When feasible, a single-stent approach extending from the LM to the LAD, traversing the LCX, is the preferred technique for managing distal bifurcation disease – particularly when the reference vessel diameter of the LCX is small (<2.5 mm) or the LCX ostium is not significantly diseased. This strategy is technically straightforward and has been associated with lower rates of target lesion revascularization compared to a two-stent approach.

Stent deployment is performed from the LM to the LAD, using the main branch (MB) reference diameter (typically the LAD) for sizing. Oversizing the stent can increase the risk of distal dissection and may also promote carinal shift, potentially leading to side-branch (SB) occlusion. To mitigate this, the proximal optimization technique (POT) is performed. POT facilitates larger strut openings toward the SB with minimal carinal displacement, thereby easing guidewire exchange. Three strategies have been described for managing the SB:

1. Crossover stenting followed by POT without SB dilatation or kissing balloon inflation (KBI).
2. If SB intervention is required, the LAD wire is withdrawn and redirected through the most distal cell adjacent to the carina into the LCX. This technique ensures optimal strut expansion at the SB ostium. The "jailed" LCX wire is then removed and reintroduced into the LAD.
3. Alternatively, a new wire can be shaped with a gentle double curve, advanced through the LM into the LAD with the tip oriented upward, and then gently pulled back while rotating the tip downward to access the LCX. Depending on the anatomy and procedural goals, this is followed by POT, KBI, and re-POT, or by POT, SB ballooning, and re-POT without KBI. (Figure 10.3).

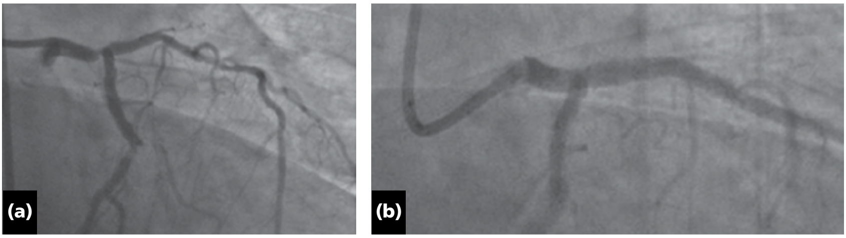

Figure 10.3 (a) Coronary angiography demonstrates severe distal bifurcation stenosis of the left main in the right anterior oblique (RAO) caudal projection. The ostium of the left circumflex artery is not significantly diseased. (b) Final angiography after a 3.5-mm × 12-mm stent was deployed across the ostium of the left circumflex into the left anterior descending artery. The left main was post-dilated with a 4-mm noncompliant balloon.

Tips and Tricks

****How to do POT?** The POT facilitates the restoration of the original physiological anatomy of the LM bifurcation. It prevents abluminal wire exchange beyond the proximal segment of the stent. To enable this, the stent should be positioned sufficiently proximal to the SB to accommodate a short, large-diameter balloon-sized according to the LM diameter and measuring at least 6–8 mm in length. The distal marker of the balloon is aligned at the level of the carina and inflated to optimize the proximal stent segment. This step enhances strut protrusion into the SB with wider strut openings, minimizes or eliminates carinal displacement, ensures proper stent expansion to match the LM diameter, corrects malapposition, and reduces ellipticity of the stented segment [9].

T-stenting Technique

T-stenting is an option if the LCX is >70° from the LAD. However, this technique is associated with high restenosis rates. With a 6-Fr guide, the wires are placed in the LAD and LCX. A stent is positioned in the LCX, and a balloon catheter is positioned in the LM-LAD. The LCX stent is deployed first with the proximal stent edge fully covering its origin while not excessively protruding into the main lumen. After the wire and stent balloon are removed, the prepositioned balloon in LM-LAD is inflated to crush the protruding stent strut in the main lumen. After the LM-LAD balloon is removed, a stent is deployed in the LM-LAD across the LCX. A wire is readvanced into the LCX for final kissing balloon angioplasty (FKBA).

Provisional T-stenting Technique

Also known as T and protrusion (TAP) technique, this is an alternative approach to T-stenting and should be considered if the angle between the LAD and LCX is ≥70°. It is also utilized if the crossover technique compromises the ostium of the LCX, resulting in suboptimal results. After predilatation of the LM, the LM-LAD stent is implanted (Figure 10.4). If the ostium of the LCX is compromised, a wire is advanced into the LCX followed by balloon angioplasty of the LCX in order to dilate the stent strut at the origin of LCX. Then, a stent is positioned in the LCX with the proximal margin protruding into the LM to completely cover the ostial LCX while a balloon is positioned in the LM-LAD. After the LCX stent is deployed, the pre-positioned LM-LAD balloon in the main vessel is inflated. FKBA is performed to complete the procedure.

Tips and Tricks

****Provisional stenting of the side branch (conversion to a two-stent strategy)** Usually, the provisional stenting of the SB is indicated by major SB dissections or compromised SB flow. The SB stent may be deployed as T-stenting when the angle between the two vessels is close to 90°. The precise deployment of the SB stent at the ostium is crucial without protrusion inside the MB. The TAP technique is a very simple approach to bail out SB stenting with a narrow bifurcation angle. The LM-LAD stent is sized to the distal vessel, and the POT is performed. The jailed wire is withdrawn, and the LCX is recrossed through the distal cell (closest to the carina). Then the LCX stent is deployed with minimal protrusion (1–2 mm inside the LM stent), while maintaining an uninflated balloon in the MB. A slight retraction of the SB stent balloon is followed by final KBI (Figure 10.4). The kissing balloon deflation should be simultaneous; otherwise, the protruded stent in the LM will keep the same position as before KBI. The TAP stenting eliminates the need for a second SB rewiring. An anticipated pitfall of this technique is the creation of a single-layer "neocarina." The length of neocarina is determined by the take-off angle of the SB and the site of strut crossing. With a T-shaped take-off, a small protrusion of the LCX stent inside the LM is required to cover the LCX ostium. In contrast, acute (Y-shaped) SB angles are associated with longer, oval-shaped SB ostia, warranting the need for wider protrusion of the stent [8].

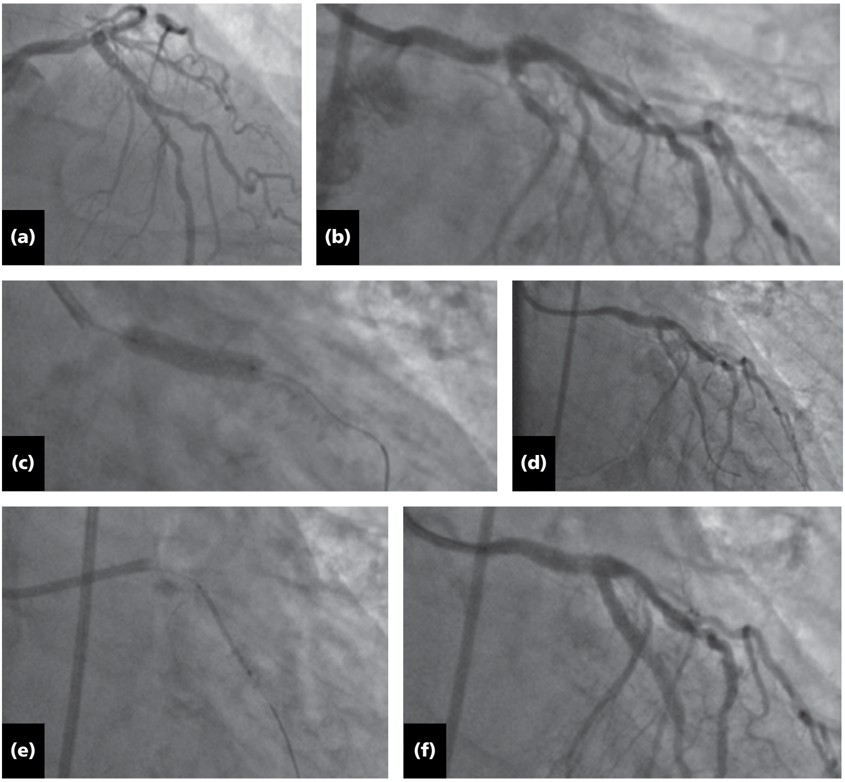

Figure 10.4 (a) Provisional T-stenting. Coronary angiography in the anterior–posterior (AP) cranial projection reveals severe distal left main (LM) stenosis. (b) Coronary angiography in the right anterior oblique (RAO) caudal projection demonstrates severe distal LM bifurcation disease with involvement of the ostium of the left circumflex (LCX). (c) A 4.0 × 18 mm everolimus-eluting stent was deployed in the LMCA into the left anterior descending (LAD). (d) Coronary angiography after stenting of the LMCA into the LAD. (e) Provisional stenting of the LCX. (f) Final angiography reveals excellent angiographic results in the distal LM bifurcation.

Crush Technique

The crush technique should be considered when the ostia of the LAD and LCX have significant stenoses, the RVD of the LCX is ≥2.5 mm, and the angle between the LAD and LCX is <70°. The crush technique requires at least a 7-Fr guide to accommodate two simultaneous stents and a supportive guide such as an extra back-up (EBU) or contralateral left support (CLS) (Figure 10.5). The LCX stent is positioned with the proximal segment protruding into the LM. The LAD stent is positioned with the proximal segment overlapping the LCX stent. The LM-LCX stent is deployed first, followed by removal of the LCX wire. The LM-LAD stent is subsequently deployed, crushing the proximal portion of the LM-LCX stent. A wire is readvanced into the LCX, and FKBA is performed to decrease MACE rates. A 6-Fr guide can be used for the crush technique if it is performed in a stepwise fashion, obviating the need for a larger guide. In this modified version of the crush technique, after a stent is positioned in the LM-LCX, a balloon is advanced into the LM-LAD rather than a stent. After the LM-LCX stent is deployed, the wire in the LCX is removed prior to the LM-LAD balloon crushing the LM-LCX stent against the wall, facilitating the placement of the LM-LAD stent. After the LM-LAD stent is deployed, a wire is readvanced into the LCX in order to perform FKBA.

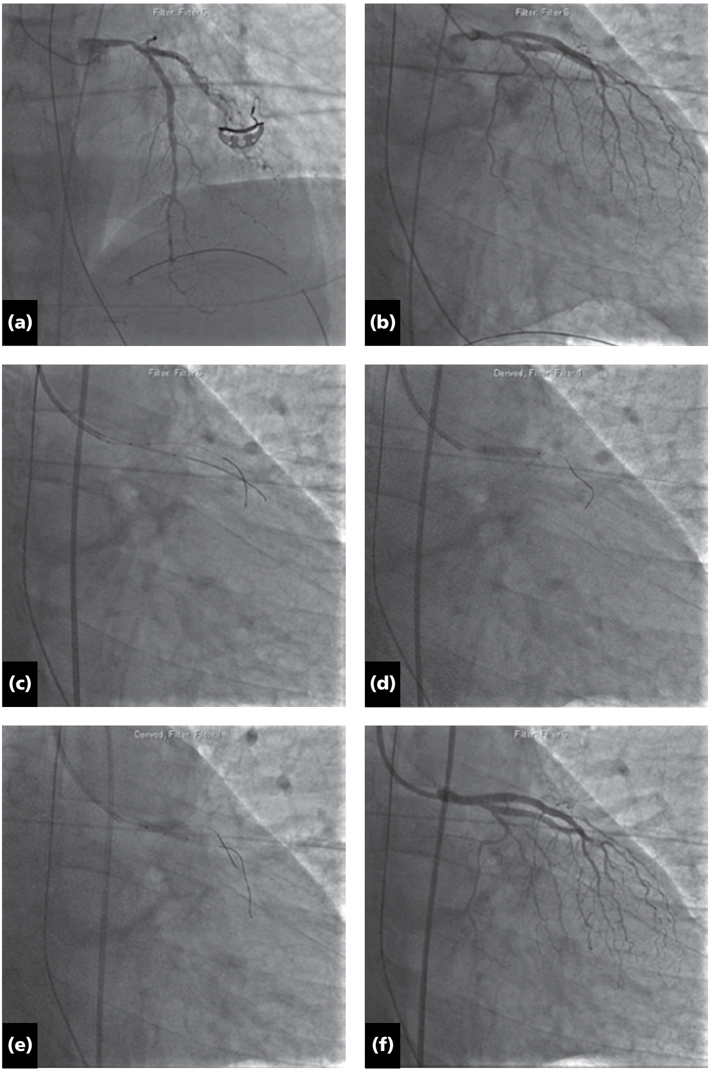

Figure 10.5 (a) Coronary angiography reveals severe distal bifurcation stenosis of the ULCMA. (b) Coronary angiography in the RAO caudal projection demonstrates a large territory supplied by the LCX. (c) Sequential crush technique is performed as the balloon is in the LM-LAD and the stent in the LCX-LM. (d) The LM-LAD stent deployed, crushing the LM-LCX stent. (e) Final kissing balloon inflation is performed. (f) Final angiography reveals excellent results.

Different Options in Recrossing the Side Branch

Difficulty recrossing the stent struts into the LCX with a workhorse wire may require the use of specialty wires like a hydrophilic wire, such as a Whisper® wire (or Pilot 50® wire), or a tapered-tip wire such as a Fielder XT® wire. Difficulty advancing a balloon across the stent struts may require a very small diameter balloon (1.2 mm). The Glider™ has a torquable shaft and unique skived tip to enhance steerability along with a 4-mm balloon length option that may traverse stent struts at the bifurcation more easily than a traditional balloon.

Mini-crush Technique

This technique is essentially the same as the traditional crush technique but differs in that the LM-LCX stent protrudes only 1–2 mm into the LM to minimize the triple layer of stent in the LM (Figure 10.6).

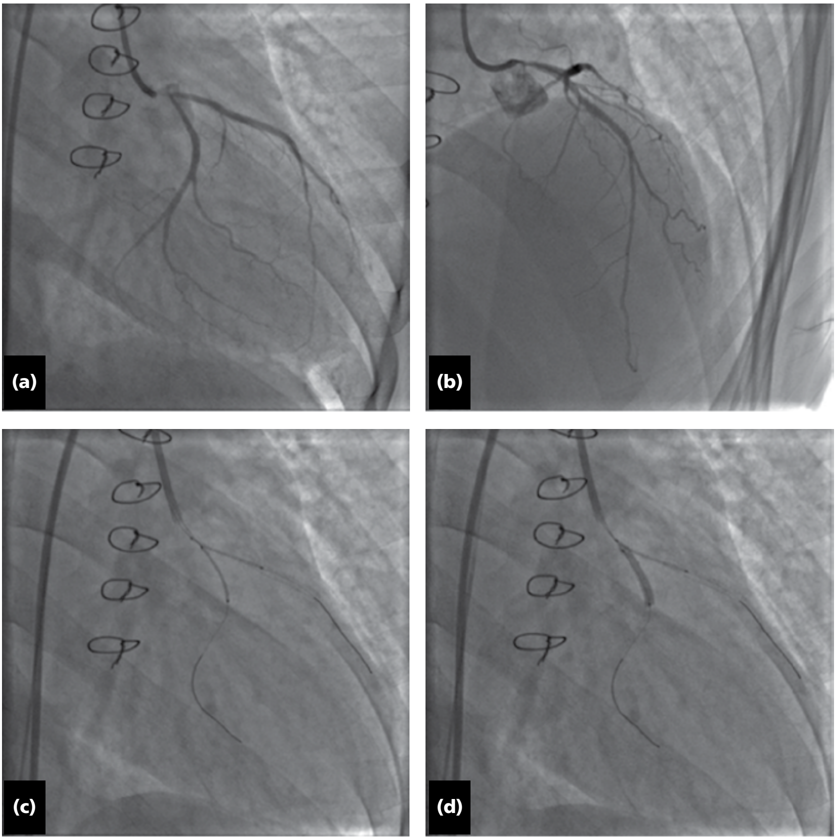

Figure 10.6 (a) Coronary angiography in a teenage patient with a history of orthotopic heart transplantation reveals severe ostial and distal bifurcation LMCA stenoses. The ostium of the LCX has at least intermediate stenosis. (b) The AP cranial projection demonstrates severe ostial stenosis. (c) In the RAO caudal position, the LM-LCX stent is protruding into the LM while the LM-LAD stent is positioned in order to "crush" the LM-LCX stent. (d) The LM-LCX stent is deployed. (e) After the LM-LCX stent is deployed and the guidewire removed, the LM-LAD stent is positioned at the ostium of the LM in the AP cranial projection. The stent is proximal to the inferior lip aspect of the LMCA but distal to the superior aspect of the LMCA. The guide catheter is disengaged at the ostium of the LMCA to allow adequate visualization. (f) Final kissing balloon angioplasty is performed. (g) Final angiography reveals excellent results.

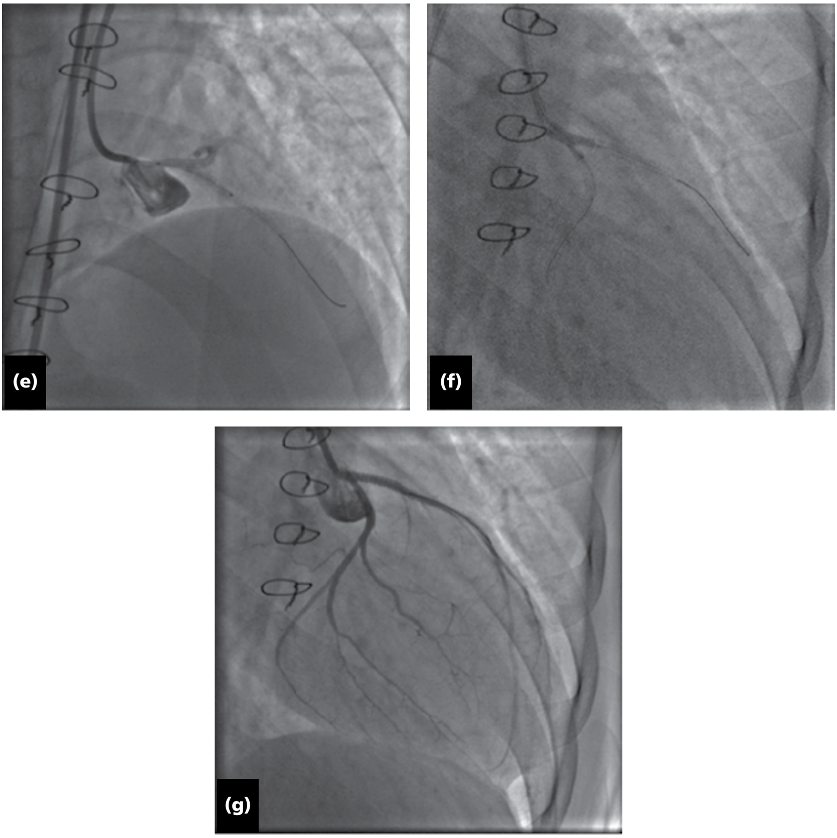

Figure 10.6 (Continued)

Double-kissing Crush Technique

This variation of the crush technique implements an extra KBI that ensures easier rewiring of the vessel. The SB stent is positioned with 1–2 mm in the main vessel; once the stent is deployed, both the stent balloon and wire are removed. The balloon in the main vessel is used to crush the SB stent. The SB is rewired, and the first KBI is performed. The main vessel stent is then deployed, and the SB is rewired. Final KBI is then performed. A randomized study that compared culotte to double-kissing (DK) crush technique in UPLMCA PCI showed a significant reduction in 12-month MACE in the DK crush arm, primarily driven by target vessel revascularization, thus demonstrating the superiority of this technique in LM interventions [10].

Simultaneous Kissing Stent (V-stenting)

Currently, this technique is rarely performed in patients with distal LMCA disease. This technique can be considered for a large LM diameter that can accommodate simultaneous stent inflations and when the LAD and LCX have severe ostial disease with relatively smaller lumen compared to the LM (Figure 10.7). A 7-Fr guide or larger is required for this technique. After predilatation of the ostia of the LCX and LAD, the proximal portions of both stents are aligned juxtaposed to each other in the LM. Stent deployment can be performed either simultaneously

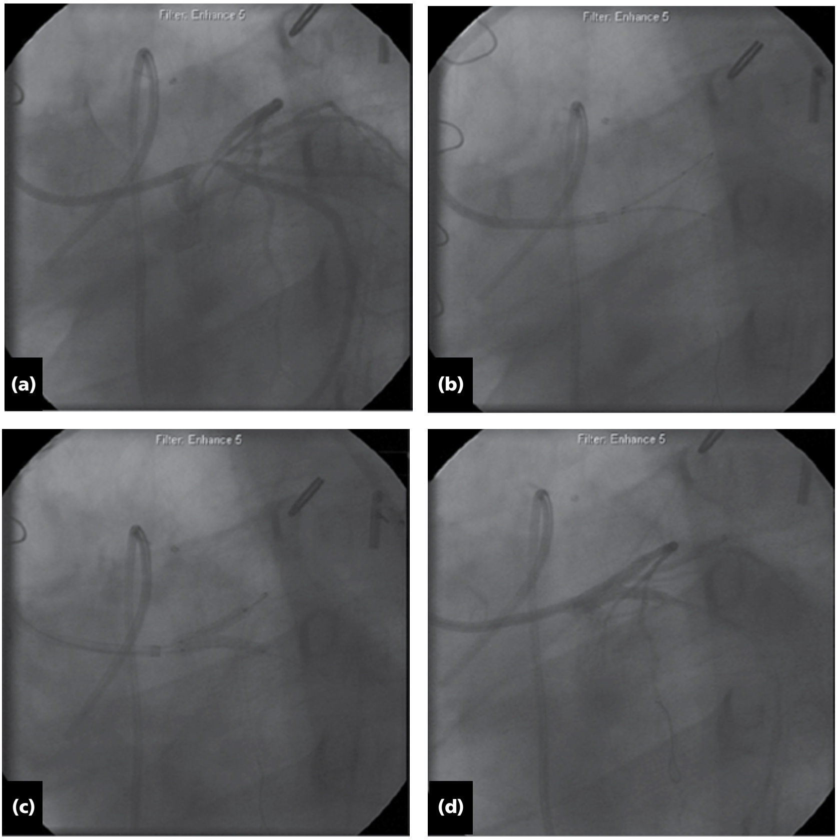

Figure 10.7 Distal bifurcation disease. A 23-year-old male status post-orthotopic heart transplantation underwent routine annual coronary angiography (a), which revealed severe disease of the distal bifurcation of the ULMCA. (b) Two stents are aligned juxtaposed to each other. (c) Two stents are inflated simultaneously. (d) Final angiography demonstrates excellent results.

with equal pressure in both stent balloons or sequentially, followed by final simultaneous inflation, resulting in the creation of a double-barreled lumen and a metallic carina. Follow-up coronary angiography may reveal a neocarina composed of intimal hyperplasia within the lumen of the LMCA; the clinical relevance of this remains to be determined. If ISR of the LM occurs, repeat PCI may be difficult as rewiring each limb of the LM stents can be challenging. An option for the treatment of LM ISR is to "crush" the neocarina into the wall of the lumen, thereby converting the double-barreled lumen to a single lumen.

Culotte Stenting

This technique can be used when the ostia of the LAD and LCX have significant disease, the LCX has a diameter ≥2.5 mm, and the angle between the LAD and LCX is shallow (<70°). A 7-Fr guide or larger is required for this technique. After predilating the ostia of the LAD and LCX, a stent is positioned and deployed in the LAD across the ostium of the LCX, with the proximal portion positioned in the LM. A wire is readvanced into the LCX, and a balloon is inflated at the ostium of the LCX to open the stent struts to facilitate stent advancement into the LCX. The second stent is advanced into the LCX with the proximal portion positioned in the LM overlapping the first stent and deployed. The LAD wire is removed and readvanced through the stent struts into the LAD in order to perform FKBA to reshape the carina. The sequence of stenting the LAD first can be reversed if the RVD of the LCX is large and if there is severe angulation. The LCX can be stented first to facilitate crossing into the LAD.

Tips and Tricks

****How to do culotte stenting** The more angulated branch, usually the SB (LM-LCX), is stented. The LAD is rewired through the stent struts and dilated. A second stent is advanced through the struts of the first into the LAD. The LM-LAD stent is then deployed. Each limb of the culotte is dilated at high pressure using noncompliant balloon, followed by final KBI at medium pressure. In contemporary culotte stenting, the POT is recommended after the first- and second-stent deployment, as well as a final POT after KBI. It is advisable to avoid a long overlap of stents in the proximal MB, whenever possible (mini-culotte). This technique ensures near-perfect coverage of the carina and the LCX ostium. The main disadvantage of the technique is that rewiring both branches through stent struts can be technically demanding and time-consuming. A bench study reports that a "napkin" or a gap usually exists at the SB ostium after culotte stenting, leading to failure to fully scaffold the ostium and resulting in increased ISR, TLR, and stent thrombosis [11]. The culotte stenting technique can be improved by performing a 'double kissing strategy' called DK culotte by optimizing the SB result with an additional KBI before stenting the MB.

Mini-crush Stenting

The SB stent is positioned in the LCX, followed by an advancement of the LAD stent. The LCX stent is pulled back into the LAD of approximately 1–2 mm and is deployed. The deployment of LAD stent crushes the proximal LCX stent against the LM wall. The LCX is rewired through the proximal stent struts of both LAD and crushed LCX stent to perform final KBI. The mini-crush technique is suitable in narrow-angled LM bifurcation (<70°). The patency of both branches is assured, making this technique useful in conditions of instability or complex anatomy. This technique provides excellent coverage of the LCX ostium. The main disadvantage is that to perform final KBI, there is a need to recross multiple struts with wire and a balloon.

UNIQUE CIRCUMSTANCES FOR ULMCA PCI

Acute Myocardial Infarction Due to Thrombotic Occlusion of the ULMCA

Acute thrombotic occlusion of the ULMCA often results in sudden cardiac death, cardiogenic shock, electrical instability, and/or a large myocardial infarction (Figure 10.8). Although no randomized trial has assessed the preferred revascularization strategy, ULMCA PCI appears to be a reasonable option, especially if perfusion can be obtained much faster with PCI compared with CABG [12]. Furthermore, the Achilles heel of ULMCA PCI, ISR, and target vessel revascularization is not as much a pressing issue at the time of the decision-making process when the patient is in extremis. The ACCF/AHA/SCAI guidelines provide a Class IIa, level of recommendation C, for emergent ULMCA PCI in the setting of acute thrombotic occlusion, especially if coronary perfusion is compromised, PCI can be performed more rapidly, and complete revascularization can be achieved [13]. Immediate reperfusion can restore hemodynamic and electrical stability while minimizing the infarct size. A multicenter, international

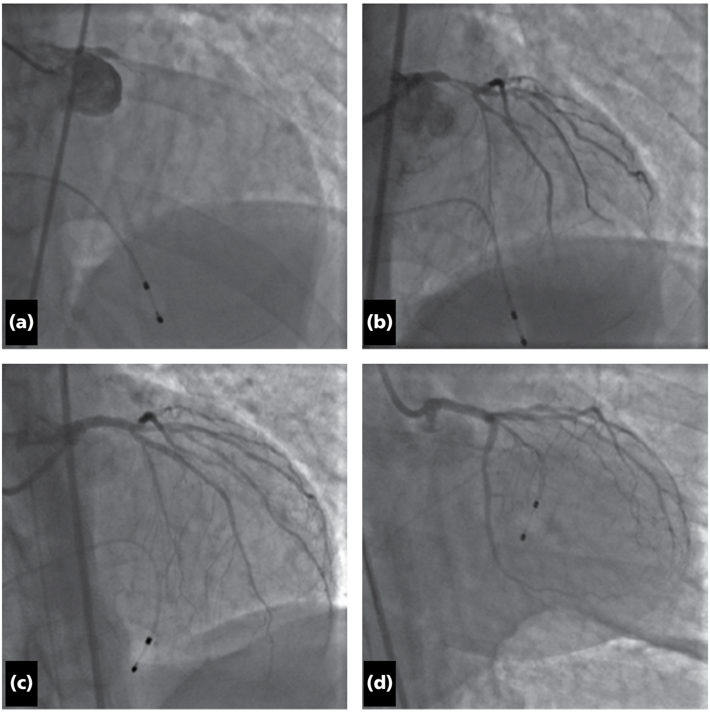

Figure 10.8 A 63-year-old male presented with cardiac arrest, return of spontaneous circulation, cardiogenic shock, and ST elevation in aVR (a). Coronary angiography reveals a thrombotic ULMCA occlusion. (b) A guidewire was advanced across the ULMCA, resulting in TIMI grade I flow. (c) Coronary angiography in the AP cranial projection reveals excellent angiographic results after stenting the ULCMA with a 4.0 × 15 mm everolimus-eluting stent. (d) Final angiography in the RAO caudal projection reveals excellent angiographic results without compromise of the distal bifurcation of the ULMCA.

registry of 62 patients who underwent ULMCA PCI for myocardial infarction reported an angiographic success rate of 100%, in-hospital mortality of 8%, and 19% mortality rate at 586 ± 431 days [14].

Hemodynamic Support Device

Patients with severe LV dysfunction who undergo ULMCA PCI represent a high-risk population of patients (Figure 10.8). In the PROTECT II trial, 452 symptomatic patients with complex three-vessel disease or ULMCA disease with severely depressed LV function were randomized to Impella 2.5® (n = 226) or intra-aortic balloon pump (IABP) (n = 226) [15]. Although the primary endpoint of 30-day major adverse events was similar for Impella 2.5 versus IABP (34.3% versus 42.2%, $p = 0.227$ in the intent-to-treat population), there was a trend toward decreased MACE at 90 days in Impella 2.5-supported patients (40.6% versus 49.3%, $p = 0.06$). Mechanical circulatory support should be considered for high-risk patients with severe LV dysfunction who undergo ULMCA PCI, especially if PCI is complex [16].

Plaque Modification for Heavily Calcified ULMCA

The presence of heavily calcified coronary lesions increases the complexity of PCI due to the inability to fully expand the stent (Figure 10.9) [17]. The rates of death, myocardial infarction, target vessel revascularization, and stent thrombosis are higher in patients with severe coronary artery calcification who undergo PCI [18]. Plaque modification of the ULMCA with rotational or orbital atherectomy is a safe and effective strategy to prepare the heavily calcified lesion prior to PCI [19, 20]. This may be particularly important given the large territory that the ULMCA supplies. Failure to adequately modify the heavily calcified ULMCA plaque may result in a suboptimally expanded stent, rendering the patient at increased risk for ischemic complications.

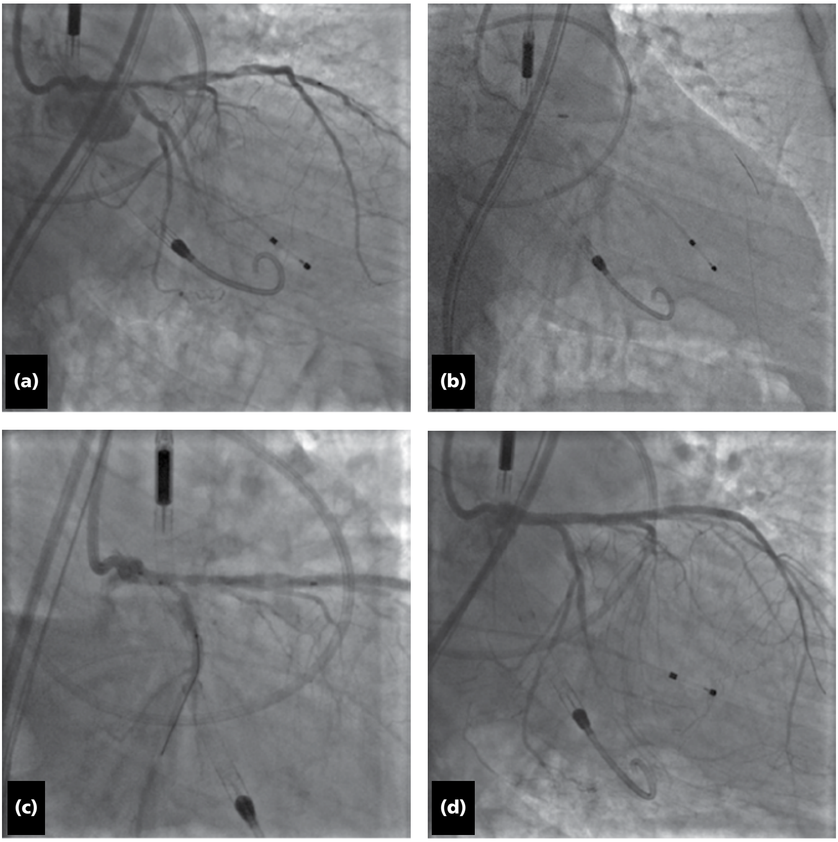

Figure 10.9 (a) Coronary angiography in an 85-year-old male with severe left ventricular dysfunction (ejection fraction 15%), stage 4 chronic kidney disease, severe restrictive lung disease, and occluded right coronary artery reveals a significant distal bifurcation stenosis of the ULMCA. An Impella left ventricular assist device was inserted to provide hemodynamic stability during complex coronary intervention. (b) Rotational atherectomy was performed to modify severely calcified plaque prior to stenting. (c) A mini-crush technique was performed in the distal bifurcation of the ULMCA. (d) Final angiography demonstrates excellent results.

Restenosis after ULMCA PCI

The restenosis rates are much higher in patients who undergo ULMCA PCI for distal bifurcation disease compared with ostial or mid-shaft lesions. The most common location for restenosis is the ostium of the LCX. While the optimal revascularization strategy is unknown for the treatment of ISR after treatment of ULMCA PCI, repeat PCI is a viable option due to its minimally invasive approach and favorable early and late results [21] (Figure 10.10). In the FAILS study, 70 (9.7%) of the 718 patients who underwent ULMCA PCI had restenosis. Of these, 59 (84.3%) were treated with PCI (34 [48.6%] with DES, 22 [31.4%] with standard or cutting balloons, 2 [2.9%] with rotational atherectomy, and 1 [1.4%] with bare metal stent). At a follow-up of 27.2 ± 15.4 months, MACE occurred cumulatively in 18 (25.7%) patients, 4 (5.7%) patients died, 2 (2.9%) patients had myocardial infarction, and 15 (21.4%) patients had target lesion revascularization. Patients treated with medical, percutaneous, and surgical therapy had MACE rates of 50%, 25.4%, and 14.3%, respectively [21].

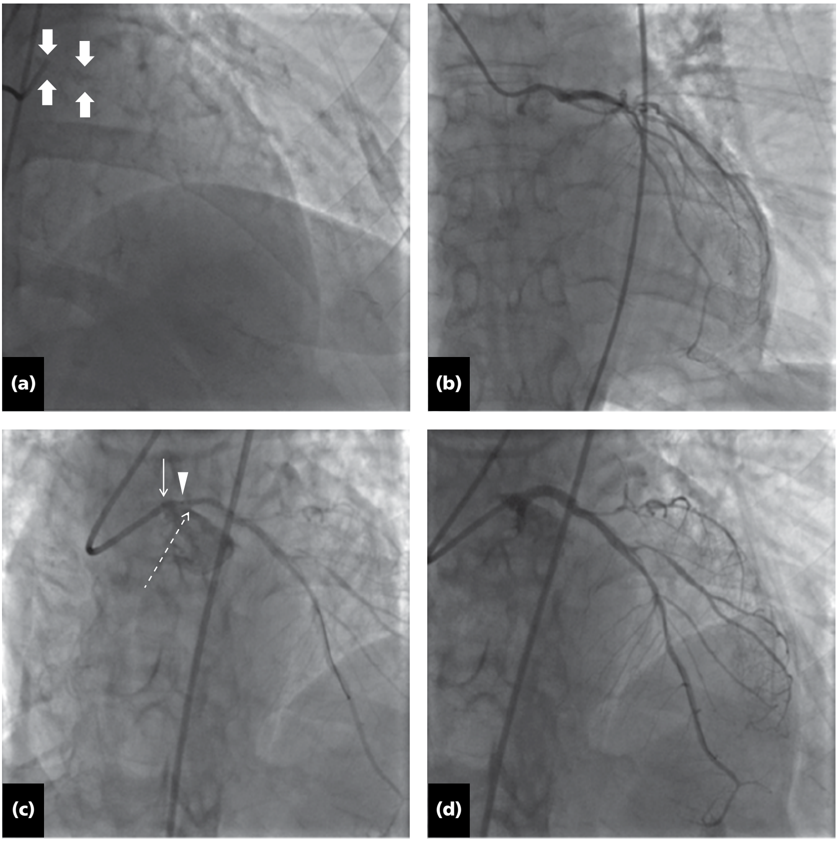

Figure 10.10 (a) Fluoroscopy reveals severe coronary calcification of the ULMCA (arrows). (b) Coronary angiography reveals severe ostial stenosis of the ULMCA. (c) A stent is placed in the cranial projection. The proximal marker of the stent (arrowhead) is distal to the superior border (arrow) but proximal to the inferior border (dashed arrow) of the ULMCA. (d) Final angiography demonstrates excellent angiographic results.

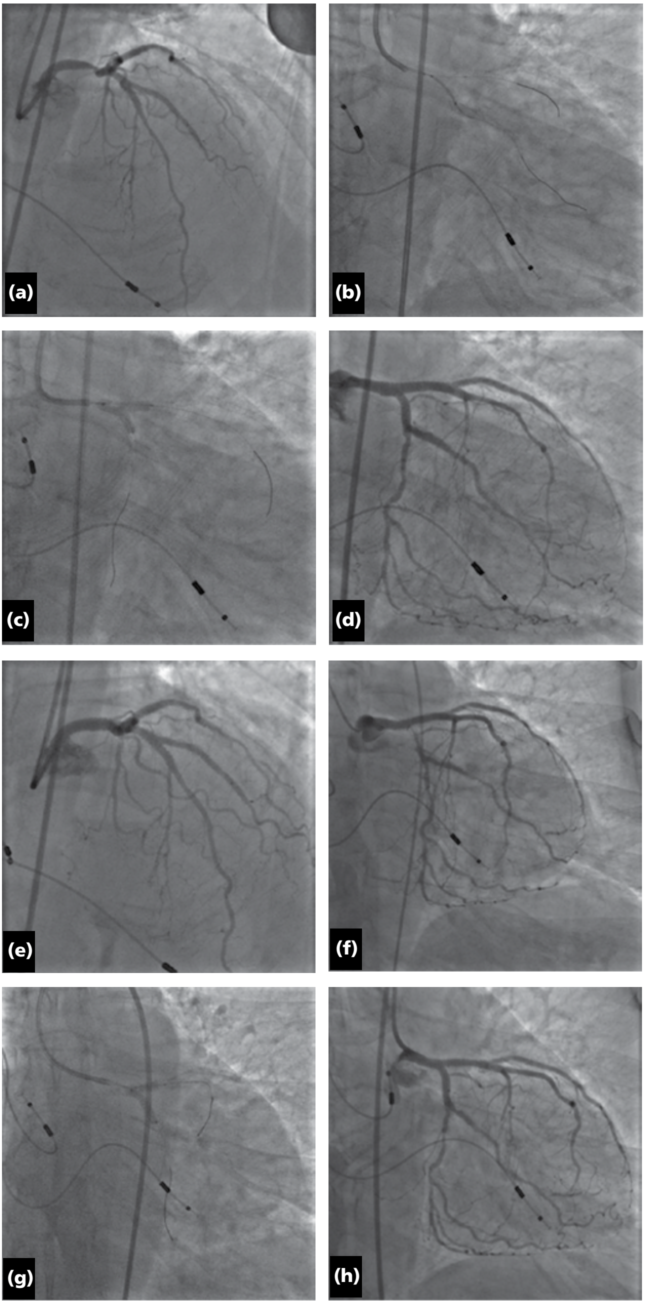

Figure 10.11 Coronary angiography of a 65-year-old female with severe distal ULMCA stenosis. (a) The ostial LCX also has severe stenosis. (b) Crush technique in a stepwise fashion was performed. A 3.25 × 15 mm everolimus-eluting stent was placed in the LM-LCX, and a balloon was positioned in the LAD-LM. (c) Final kissing balloon angioplasty was performed with a 3.25 × 15 mm noncompliant balloon in the LM-LCX and

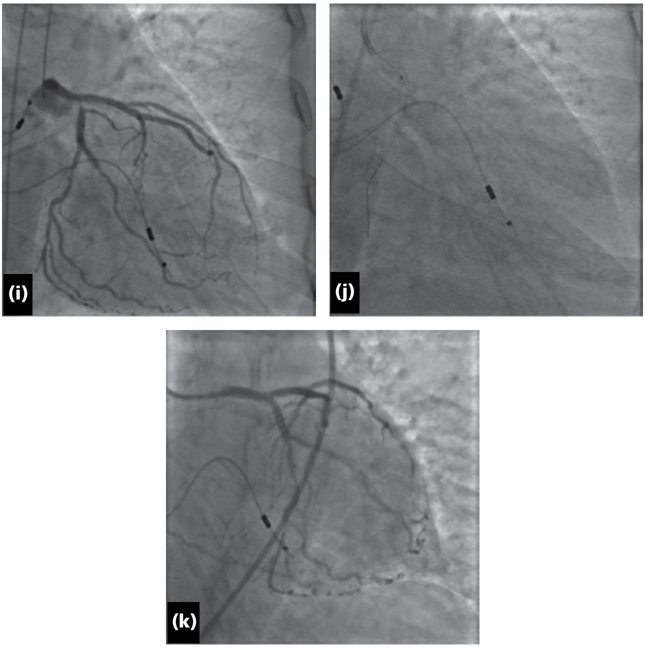

Figure 10.11 (Continued) 3.5 × 15 mm noncompliant balloon in the LM-LAD. (d) Final angiography in the RAO caudal projection reveals good angiographic results. (e) Final angiography in the AP cranial projection reveals good angiographic results. (f) Coronary angiography was performed 7 months after ULMCA PCI because of chest pain. The ostial LCX has severe in-stent restenosis. (g) Another 3.25 × 15 mm everolimus-eluting stent was implanted in the ostium of the LCX followed by kissing balloon angioplasty. (h) Final angiography after repeat PCI with DES. (i) The patient developed recurrence of chest pain. Coronary angiography revealed recurrence of severe in-stent restenosis in the LCX. (j) The patient received cardiac surgery consultation. However, she refused CABG and wanted to undergo repeat PCI. Laser atherectomy of the in-stent restenosis of the LCX was performed by balloon angioplasty with a 3.5-mm non-compliant balloon. (k) Final angiographic images demonstrate that in-stent restenosis in the LCX has decreased.

KEY POINTS

ULM disease can be successfully treated by PCI with DES in selected patients, particularly those with low or intermediate SYNTAX scores. PCI is the preferred treatment option for selected patients, especially those with acute myocardial infarction due to thrombotic occlusion, isolated ULMCA or concomitant single-vessel disease, and ostial or mid-shaft lesions, and those who undergo elective PCI.

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CHAPTER 11

Chronic Total Occlusion

Debabrata Dash, Vu Hoang Vu, and Thach N. Nguyen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

According to the Chronic Total Occlusion Academic Research Consortium (CTO-ARC) definitions, CTOs are defined as the absence of antegrade flow through the lesion with a presumed or documented duration of >3 months [1]. The antegrade approach is defined as when the occlusion segment was approached from the proximal CTO cap with the intention of crossing the distal CTO cap into the distal true lumen. Retrograde is defined as when the occlusion segment was approached from the distal CTO cap with the intention of crossing the proximal CTO cap into true lumen. Wiring of the CTO lesion is defined as follows: intraplaque means that the CTO is intentionally crossed through the CTO body. Extraplaque means that the CTO is crossed through a dissection plane followed by reentry into the true vessel lumen at or beyond the reentry point.

Extraplaque wiring can be performed antegradely or retrogradely, defining the terms of antegrade dissection and reentry (ADR) and retrograde dissection and reentry (RDR), respectively [2].

The antegrade group includes those procedures in which the CTO lesion is finally crossed by true anticipated antegrade wire escalation (AWE) without retrograde or ADR contribution. Additionally, the antegrade group includes alternative antegrade crossing strategies, and the CTO lesion is finally crossed by AWE with retrograde contribution (AWE-R) and those in which the CTO lesion is finally crossed by ADR with retrograde contribution (ADR-R) or ADR without retrograde contribution (ADR-0). The retrograde group includes those procedures in which the CTO is finally crossed retrogradely, by retrograde wire escalation (RWE) wiring or RDR techniques. The term rescue or bailout approach in the context of CTO percutaneous coronary intervention (PCI) reflects the final approach following other failed previous crossing attempts [2].

Necessary Skill Sets for a CTO Operator

Prior to embarking on PCI for CTO, the operator must be adept at all aspects of complex non-CTO PCI. This includes working knowledge and experience of all forms of atherectomy, direct intravascular imaging interpretation, and pericardiocentesis [3]. The operator must have an excellent theoretical understanding of appropriate case selection and indications for CTO PCI, and the ability to calculate angiographic risk scores to determine procedural complexity. Besides basic essential knowledge, further advanced training requires live attendance at a training course, seminars at regional centers of excellence, and on-site proctoring. The operator can escalate the complexity of cases as experience and proficiency improve along the learning curve.

PREPROCEDURAL INVESTIGATIONS

Investigating the History

In CTO older than 1 year, neovascular channels with a diameter of 100–200 mcg are the main features in pathological studies. These neovascular channels are often connected with the vasa vasorum in the adventitia, whereas the channels in a more recent CTO (filled by thrombus <1 year old) communicate with the distal lumen through recanalization channels [4]. This is why knowledge of the age of the lesion is crucial in selecting the right type of wires [4]. The younger CTO lesions are observed to be predominantly soft or lipid laden, whereas older lesions are typically hard or calcified. The success of guidewire crossing in CTO PCI might be affected by loose fibrous tissue, pultaceous debris, or intimal plaque microchannels [5]. During the interview with the patient, a history of myocardial infarction (MI) would be helpful in identifying the start of the CTO. Morning angina, or angina at the start of low-level activity that is relieved with further exercise, is very suggestive of a CTO. The reason for angina relief with further exercise is that the ischemic stimulation (exercise) recruits (or opens) the collateral channels (CCs). Review of a previous diagnostic angiogram if available would also help to date the CTO [4].

Scouting the Terrain

The need to scrutinize the diagnostic angiography frame by frame and from different angles can never be emphasized enough. Look for any dimple at the CTO lesion and find any potential recanalization channels or existing lumina inside the CTO. Calcification within the lesion is often an indicator of the vessel shape; thus, it may be useful to delay the injection of contrast for a few heartbeats, recording a short plain cine for better delineation of the calcification [4].

When the proximal and distal portions of the occlusion seem to slip out of alignment with each heartbeat, it is a sign of tortuosity within the CTO [4]. It is crucial to have a clear image of the distal vasculature in order to estimate the length of the CTO lesion. If the CTO is wrongly assessed to be long, an operator could set the distal reentry point too far down and fail to realize that a long false lumen has been created [4].

It is important to identify the main CCs, and the vessel supplying and receiving them, so that a supporting balloon catheter would not obstruct the collateral antegrade flow if the balloon-anchoring technique is needed. One pitfall is the presence of collaterals from a conus branch to the left anterior descending (LAD) artery. A conus branch can be separated from the right coronary artery (RCA) ostium and missed if only angiography of the main RCA is done [4].

Tips and Tricks

****Contralateral injection** The information from the contralateral injection is very important to monitor the wire movement. However, if there is interference between an interventional guide and a diagnostic catheter, one should access it via the radial approach [4].

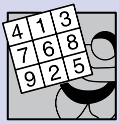
*****How to use less contrast** To reduce the amount of dye used, contralateral injections may be performed by superselective injections with a microcatheter deep in the collateral branch [4]. Likewise, antegrade injections may be made via the microcatheter to visualize the distal vessel.

*****How to reduce radiation exposure** CTO operators must be comfortable working at 7.5 frames per second and on a 20-cm field of view. In this way, radiation dose to the patient and scatter dose to the operator and staff can be minimized. Techniques such as "fluorostore" and "trapping" further allow for minimizing radiation exposure [6].

Multislice Computed Tomography

Multislice computed tomography (MSCT) is an imaging modality that could outline the shadow of an angiographically invisible and totally occluded artery. The possible information provided by MSCT includes (1) visualization of an occluded artery and collateral vessels; (2) length and diameter of the vessel within the occluded segment; and (3) morphology of a CTO lesion. Calcifications >50% of the cross-sectional vessel area alone or in combination with an occlusion length of >15 mm in MSCT predict the failure of CTO PCI [7]. The Computed Tomography Registry of Chronic Total Occlusion Revascularization score represents a simple and accurate noninvasive tool for predicting time-efficient guidewire crossing that may aid in grading CTO difficulty before PCI [14].

GAME PLAN



Which Strategy?

Detailed examination of the diagnostic angiography enables the operators to gather substantial working understanding of the anatomy of the CTO lesion and related coronary arteries. This wealth of knowledge allows the operators to formulate a game plan according to the CTO-ARC for complex CTO PCI. The various strategies include [2]:

1. Antegrade wire escalation without retrograde contribution (AWE-0)
2. Antegrade dissection and re-entry without retrograde contribution (ADR-0)
3. Antegrade wire escalation with retrograde contribution (AWE-R)
4. Antegrade dissection and re-entry with retrograde contribution (ADR-R)
5. Retrograde wire escalation (RWE)
6. Retrograde dissection and re-entry (RDR).

At first, the primary strategy is selected based on the anatomic characteristics of the CTO lesion and the involved coronary arteries. Then, a subsequent secondary and tertiary strategy is mapped, prepped, and executed depending on the success, failures, or complications of the first or second strategy [9].

A more fundamental change has been the evolution of a "global" approach to procedural strategy to achieve procedural success in the most efficient and expedient fashion [10]. This has been further modified by the author to encourage discussion, promote research, facilitate training, and improve outcomes of CTO PCI (Figure 11.1) [11].

The AWE is a technique where a guidewire penetrates the proximal cap of the CTO and aims to remain intraplaque before entering the distal true lumen. This strategy is started most frequently (or first) when the proximal cap of the CTO is unambiguous, the lesion length is short, and the distal landing zone is in a healthy segment of the vessel and not at a bifurcation. The cutoff for length proposed in the hybrid algorithm is 20 mm, but with the advent of newer generation wires longer lesions in straight segments can also be successfully crossed using AWE techniques. Although AWE is the most frequently used and the most frequently successful strategy, ADR becomes a valuable bailout option when AWE fails to reach the distal true lumen and acquires an extraplaque situation. ADR can also be used as a first-line strategy in case of long (>20 mm) occlusions with an ambiguous or impenetrable proximal cap or, again, in case of an ambiguous or tortuous vessel course (Figure 11.1).

The antegrade technique by default remains the primary approach because it may be successful and whether or not it fails, antegrade preparation is required for completing the retrograde crossing.

Retrograde CTO PCI (RWE or RDR) is most commonly favored when an antegrade approach is unsuccessful. However, for selected lesions, an upfront (primary) retrograde approach is also favored like flush aorto-ostial CTOs, tortuous CTO course, CTOs with proximal cap ambiguity, bifurcation at the distal cap, severe proximal tortuosity or calcification, diffuse disease or poorly visible distal vessel, and CTO vessels like anomalous coronary arteries that are difficult to engage. Dedicated tools along with an operator expertise, in addition to appropriate CCs, are critical to the success of retrograde CTO PCI [12, 13].

ANTITHROMBOTIC AND ANTICOAGULANT

Procedural anticoagulation considerations are similar to PCI of non-CTO lesions, except that direct antithrombins and glycoprotein IIb/IIIa inhibitors are usually avoided because anticoagulant reversal cannot be achieved if there is perforation. Unfractionated heparin (UFH) may be administered before angioplasty with an initial reduced dose to achieve an activated clotting

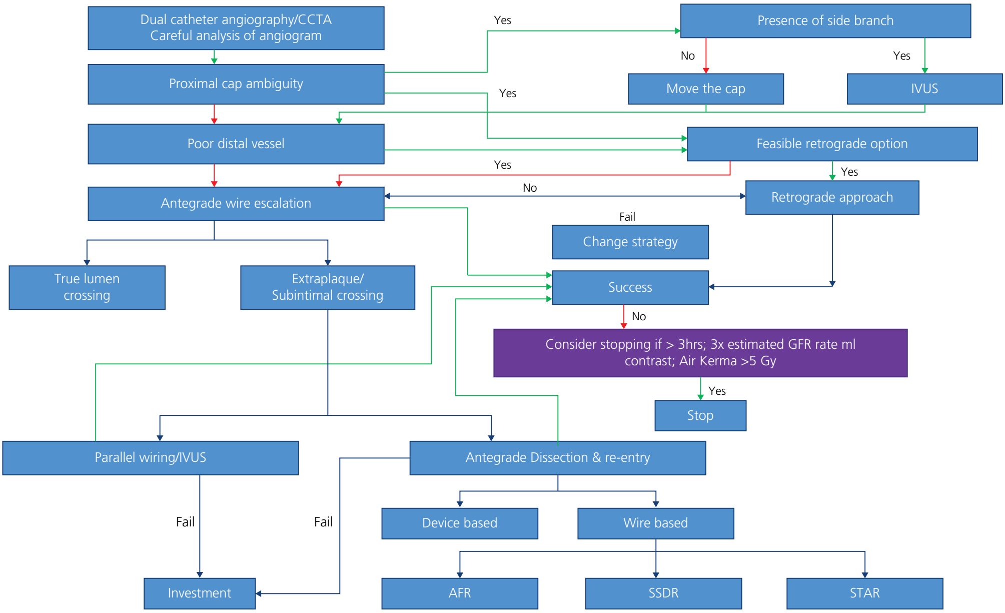

Dual catheter angiography/CCTA
Careful analysis of angiogram
Yes
Presence of side branch
No
Yes
Proximal cap ambiguity
Yes
Move the cap
IVUS
Poor distal vessel
Feasible retrograde option
Yes
Yes
No
Antegrade wire escalation
Retrograde approach
Fail
Change strategy
True lumen crossing
Extraplaque/ Subintimal crossing
Success
No
Consider stopping if > 3hrs; 3x estimated GFR rate ml contrast; Air Kerma >5 Gy
Yes
Stop
Parallel wiring/IVUS
Antegrade Dissection & re-entry
Fail
Fail
Device based
Wire based
Investment
AFR
SSDR
STAR

Figure 11.1 Schematic illustration of steps of retrograde approach. Abbreviations: CAG, coronary angiography; CC, collateral channel; CTO, chronic total occlusion; CART, controlled antegrade and retrograde subintimal tracking; rCART, reverse controlled antegrade and retrograde subintimal tracking; IVUS, intravascular ultrasound.

time (ACT) of approximately 200 s until the wire has successfully crossed the CTO. After that, additional UFH should be administered before dilatation to achieve an ACT of >250. ACT should be checked every 30 minutes [3]. With a retrograde approach, however, it is mandatory to keep ACT >300 s in view of the risk of donor artery thrombosis with inadequate anticoagulation.

SHARP THINKING

When to Stop

Variables that favor terminating an unsuccessful but as-yet-uncomplicated procedure include:

1. Reaching the upper limits of radiation exposure (e.g. 60 minutes of fluoroscopy time).
2. Reaching 3 hours of procedure time or air kerma (kinetic energy released per unit mass radiation) dose of >5 Gy.
3. Dye consumption 6 × glomerular filtration rate in mL, typically 600 mL in a nondiabetic patient with normal renal function; much lower in patients prone to contrast nephropathy.
4. Creation of a large false lumen, especially if adventitial staining is present.
5. Shearing off collaterals resulting in loss of visualization of the distal vessel.
6. Excessive patient or operator fatigue.

A second attempt after a failed CTO attempt (usually performed 6–8 weeks later to allow vessel healing) may be successful in >50% of patients, especially when the mode of failure is understood and a feasible alternative strategy has been formulated.

VASCULAR ACCESS

Femoral artery access is acceptable for CTO intervention with utilization of 7- to 8-Fr guides for passive support; 6- to 7-Fr guides are used by operators skilled at active guide manipulation through the radial approach. If there is a need for contralateral injections, a 4- or 5-Fr catheter can be inserted into either the contralateral femoral or radial artery [4].

GUIDES

The choice of guide is very important because, without adequate support, it may be impossible to push the wire or balloon across a CTO lesion. The principles of strong guide backup include:

1. large guide size (the larger the better)
2. large opposite aortic wall contact area
3. support from the root of the aorta
4. great (perpendicular) angle between the ascending aorta and the main distal segment of the guide (between the primary and secondary curves).

A 7- or 8-Fr size guide is needed to accommodate a double microcatheter (seesaw technique), intravascular ultrasound (IVUS) catheter (safer in 8 Fr), anchoring technique, and reentry catheter. Larger guides provide the versatility to pass covered stent grafts more easily should a perforation occur, a complication that must be anticipated with PCI of CTOs.

Another important factor for the guide in CTO is a soft tip, which is required when the guide needs to be deep-seated in the proximal RCA or left circumflex artery (LCX) or LAD to increase backup. Usually, the left Amplatz (AL) or left extra-backup (EBU) design guide is selected for LCX or LAD lesions and an AL shape or right EBU design guide is selected for an RCA procedure. There is no role for the Judkins left guide in PCI of complex CTO because it cannot be advanced deeply (and safely) into the left main (LM). The RCA guide can have side holes (if desired) to allow perfusion of the sinus node and conus branches during deep-seating. Aggressive manipulation of the guide or inadvertent deep intubation (which does occur infrequently with the Amplatz guide) may dissect the RCA ostium (often requiring stenting), a complication that should be anticipated and recognized before wire removal [4].

QUICK ACTION

Sudden Decrease in Blood Pressure and Tachycardia

Caution: When an EBU or Amplatz-type guide is used in a "power position", this might create guide-induced aortic regurgitation (because the secondary curve prolapses into the ventricle causing incomplete closure of the aortic valve and thus acute aortic regurgitation). Sudden development of shock or tachycardia is the warning sign of this complication and can usually be resolved promptly by repositioning the guide.

GAME PLAN

Rationale for Guide Selection and Deselection

During PCI of CTO, if a guide keeps backing out as the wires or devices are advanced, it has inadequate backup. There is a need to stabilize the guide. The first corrective maneuver is to reposition the guide, put it in power position (active position), or deep-seat it. If it works, then it is great. If not, the guide should be changed for one that is larger or has a different shape in order to have better backup support from the aorta (passive support) or better coaxial transition (less trauma, no angle between the tip of the guide and the ostial segment).

If the design shape and position of the guide are optimal, the proximal segment of the index artery (especially the LCX) should be scrutinized. If there is proximal tortuosity, the next step is to add a second, stiffer wire. However, if the guide has no large area backup from the opposite aortic wall and the proximal segment of the index artery is tortuous or very calcified, adding another wire may not solve the inability to advance a device. If there is no lesion in the proximal RCA or LM, a soft-tip guide could be used and inserted deeply in the RCA or LM for support (mother-and-child technique) [4].

Tips and Tricks

***Misleading angiographic view** One of the reasons why the guide might not be stable in cannulating the RCA is because the RCA might come from a benign anomalous origin (too anterior in the right sinus). It may therefore exit the aorta on a steep angle in the sagittal plane, whereas on the anterior–posterior view, it looks normal (see Figure 2.6).

****Guide stabilization by wire anchoring** We add a second, stiffer wire and advance it to a side branch (SB) proximal to the CTO lesion. Backup strength is lower than balloon anchoring; however, the wire provides better coaxial alignment for the guide, especially when a strong support-type wire is used [14].

*****Guide deep-seating with a balloon** In the attempt to cross a CTO with a (first) wire, a proximal calcified fibrous cap can sometimes be hard to penetrate. In such a situation, if there is some space in the lumen proximal to the CTO, an over-the-wire (OTW) balloon can be positioned there and inflated. The OTW balloon provides a better backup force for manipulation of the wire tip (Figure 11.2). The guide can be deeply engaged by gently advancing it while at the same time pulling back the inflated balloon system. The size of

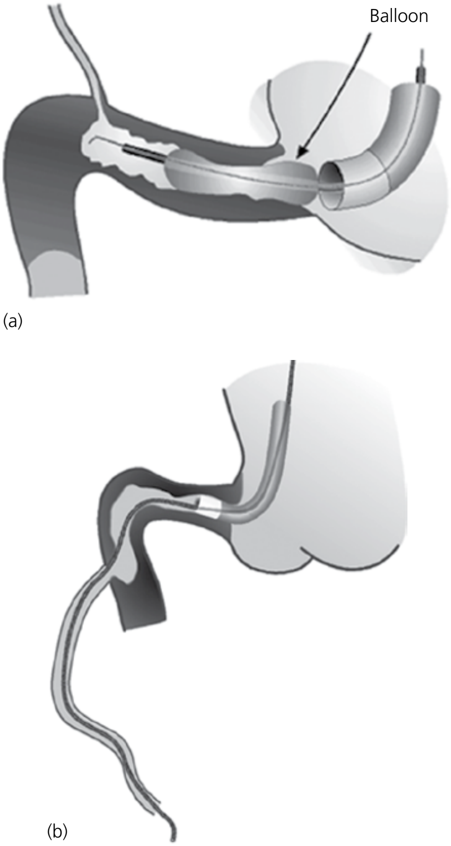


Figure 11.2 (a) When a stiff wire has failed to penetrate a proximal fibrous cap, an OTW balloon is inflated proximal to the occlusion as a support catheter for wire handling. The inflated balloon makes an extra backup force for the wire tip to penetrate the proximal cap. (b) Anchor wiring into a proximal branch also provides better backup force.

the OTW balloon must match the diameter of the segment proximal to the CTO (usually 1.25–1.5 mm diameter). Careful attention should be paid not to create a false channel in the proximal end of the CTO lesion [14].

*****Guide stabilization by balloon anchoring** Advance a small balloon to an SB located proximal to the CTO and then inflate the balloon. The inflated balloon plays a role in stabilizing the guide and provides the extra backup force. However, to prevent damage to the SB, careful attention must be taken during wire positioning and in balloon sizing. In this technique, a guide with a large lumen (8 Fr) may be required to accommodate the two balloons [14] (Figure 11.3).

*****Stabilization of the guide with another, smaller guide** A smaller straight guide can be inserted inside a larger guide in order to strengthen it. This is the case in the 5-Fr Heartrail™ straight guide, which is 120 cm in length, whereas the 6-Fr guide is 100 cm long. The 5-Fr Heartrail guide has a very soft 13-cm end-portion. This soft end-portion can easily negotiate the tortuous coronary artery with minimal damage. The inner lumen of the 5-Fr Heartrail guide is 0.059 inch in diameter; it can accept normal balloons or stent delivery systems less than 4.0 mm in diameter. The inner lumen of the outer 6-Fr guide should be more

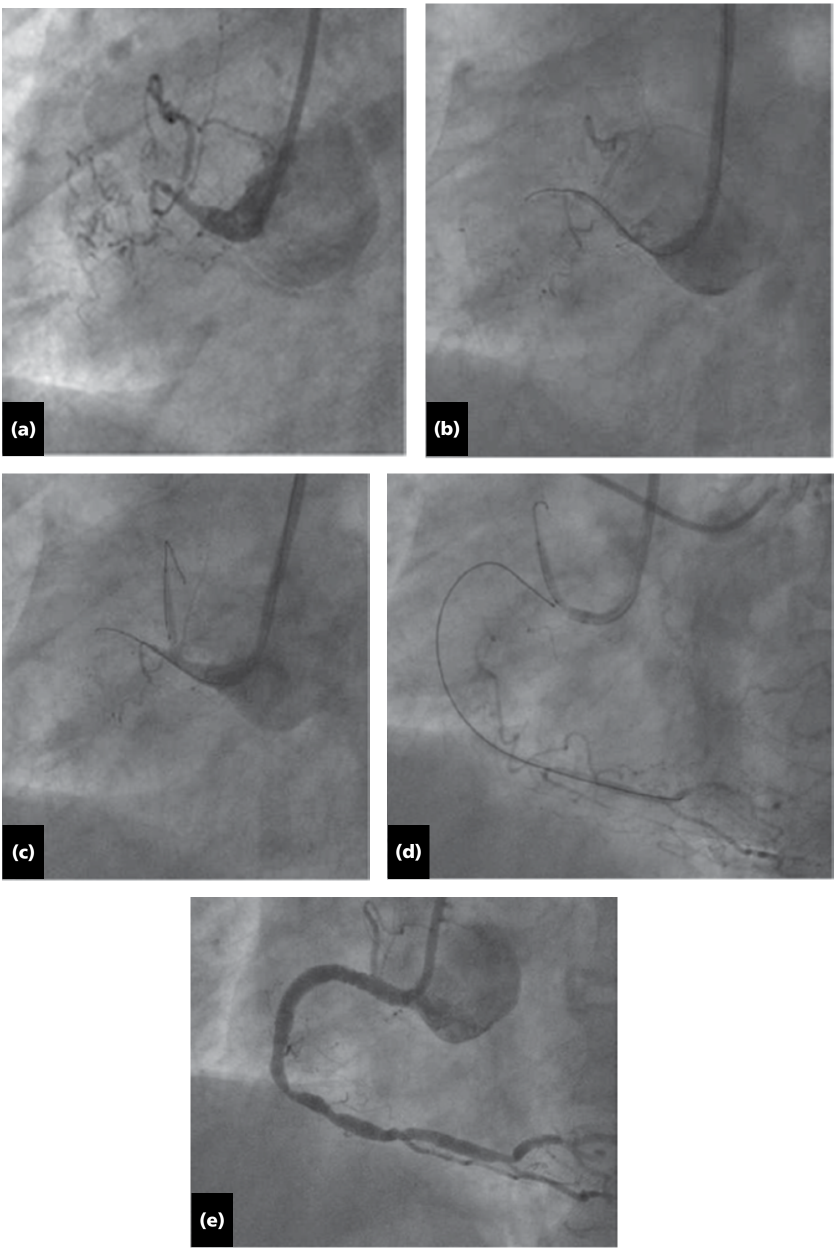


Figure 11.3 Case example with anchoring technique. (a) The proximal RCA was completely blocked with bridging collaterals. (b) A Judkins-type catheter was used to prevent damage to the RCA ostium. However, the presence of tight plaque in the CTO caused unstable backup support of guide during the wire handling. Hence, the wire could not be advanced intentionally. (c) A 2.5-mm balloon was inserted and inflated with low pressure in the conus branch to stabilize the guide. (d) With the use of this anchoring balloon, the wire control was improved, and the occlusion was successfully negotiated. (e) Final angiographic result after stenting.

TOP PERFORMANCE

Mother-and-Child Technique with a Smaller Guide

First, the balloon or the stent is removed from the 6-Fr guide. The Y connector is also removed. Second, a 5-Fr guide is inserted along the wire inside the 6-Fr guide. At this point, the 5-Fr guide should not protrude out of the tip of the 6-Fr guide. Finally, the Y connector is connected to the 5-Fr guide and PCI can restart. Before the 5-Fr guide is advanced into the target artery, a balloon catheter is advanced near the target lesion in the artery. Keeping a slight tension on the balloon catheter, the 5-Fr guide is advanced slowly in order to avoid possible injury to the coronary artery by the tip of the 5-Fr guide [15].

In this technique, careful attention needs to be exercised because there could be trauma to the index vessel resulting in dissection or the possibility of air embolism, usually occurring during intubation of the child catheter or during angiography performed via the mother guide [16]. Currently, two varieties of child-in-mother catheter are available: GuideLiner® and GuideZilla™.Guideon™.

than 0.071 inch in diameter to accommodate the 5-Fr Heartrail guide. The Launcher®, Heartrail™, and Radiguide guides also have a large inner lumen diameter.

*****Encasing a guide with a long sheath** When working with an unstable guide, a long sheath can stiffen and support the guide, depending on how far the sheath is advanced near the tip of the guide. The closer the sheath is to the coronary ostium, the more backup the guide provides.

At first, a sheath is advanced, its tip positioned in the aortic arch, and the interventional device advanced. If it is still impossible to advance the device to the intended location, the sheath is advanced further, close to the tip of the guide. As the sheath advances over the guide, it straightens the secondary and tertiary curves of the latter, causing the tip of the guide to move forward. Therefore, guides with relatively simple curves are probably safer and better suited for this technique. In order to avoid injury to the coronary ostium and dissection of the proximal segment of the coronary artery, instead of holding the guide fixed in place during the advancement of the sheath, a gentle reverse traction on the guide is advised so that its tip does not move forward. The operator should watch the guide tip continuously on fluoroscopy during this maneuver and should ensure coaxial alignment of the guide in two orthogonal views. Disengage the guide from the coronary ostium only after the sheath has been moved away from it, probably to the descending aorta, with the guide fixed in place. Just pull the sheath away; the guide will disengage due to reconstitution of its curves [17].

Of all the options mentioned above, the best techniques for strengthening a guide are ranked according to efficacy, user-friendly characteristics, and cost-effectiveness in Box 11.1.

BOX 11.1 TACTICAL MOVE

Best Options for Strengthening a Guide

1. **No added cost FIRST Best Maneuver:** Put the guide in power position or deep-seat the guide
2. **$ SECOND Best Maneuver:** Add a second, stiffer wire
3. **$$ THIRD Best Maneuver:** Change to a stronger guide
4. **$** Use the balloon-anchoring technique
5. $$ Insert a smaller straight guide inside the current guide
6. $$ Remove the guide and use a child-in-mother guide system
7. $$ Remove everything; change the short sheath to a longer one

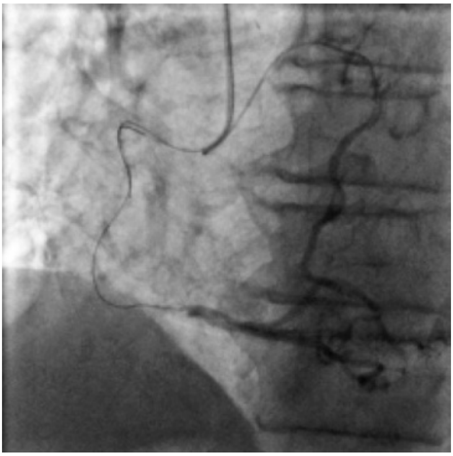


Figure 11.4 One guide to visualize two arteries. A CTO lesion was recognized in the RCA. Collaterals were visualized by contralateral injection through a microcatheter inserted in the LAD. Source: Reproduced with permission from [12] / John Wiley & Sons.

*****One guide for two arteries** After local anesthesia, a 5-Fr sheath was inserted from the left radial artery. Heparin 6000 IU was intravenously injected. A Heartrail II SL4.0 guide was engaged in the LCA first. A Runthrough® wire and a Michibiki microcatheter were inserted into the distal LAD. While the Michibiki microcatheter was placed deeply in the LAD, the guide was cautiously rotated in a clockwise direction and the tip of the guide was engaged at the ostium of the RCA. For stabilization of the guide, a Runthrough wire was inserted into the RCA as a dummy wire. The PCI was then carried out as usual in the RCA with contralateral injection at the LAD via the Michibiki microcatheter (Figure 11.4).

The keys to success in this tip are the selection of a microcatheter with an inner diameter as large as possible; the use of a dummy wire to stabilize the guide; and the selection of a guide with a high flexibility of retroflexion for dual engagement [18].

WIRES

CHALLENGES

If there is an angiographically tapered occlusion, the tapering stump is the starting place to probe the CTO. It frequently contains small recanalized channels (≥200 μm in diameter), which are potential routes for wire crossing. However, if the stump is eccentrically oriented, there is a higher risk of extraplaque wire passage and vessel perforation. When there are extensive bridging collaterals (caput medusae), the chance of wire crossing is low. The reason is that these intracoronary collaterals consist of dilated vasa vasorum, which are very fragile and easily perforated. Blunt (non-tapered) occlusions can be difficult to cross, especially when there is an SB arising near the entry site of the CTO. The concept that a plaque typically builds up on the opposite side of the origin of an SB may help the operator identify the true vessel course. However, the wire will often repeatedly deflect into the SB, and it may be difficult to penetrate the proximal fibrous cap [4].

In order to cross the CTO into the true distal lumen, the challenges that the wire has to overcome include (1) piercing the proximal cap, (2) traversing the length of the CTO, (3) piercing the distal cap, and (4) reentry into the distal true lumen.

PIERCING THE PROXIMAL CAP

GAME PLAN

There are three different strategies for piercing the proximal cap: drilling, penetrating, or sliding. The drilling strategy implies the gradual step-up of wire stiffness according to lesion complexity, relying upon visual as well as tactile feedback information from the wire tip. The penetrating strategy implies the use of direct pressure at a point in order to cross into the distal true lumen with controlled or limited rotation of the wire. The sliding strategy is used to slide a hydrophilic wire into the distal segment. Each method has advantages and disadvantages; overall, all three methods work well for the short, focal, straight segment of a noncalcified occlusion. In complex types of CTO lesion (i.e. calcification, long lesion, and severe tortuosity), the choice of a spring-type wire, and subsequent step-up stiffness in the same group, would be superior to exchanging to a different family of wires.

Discriminating Differences: Wires for CTO

Wire technology has advanced significantly, making it possible to treat complex CTOs. The choice and application of guidewires are crucial for CTO PCI, especially when using a wire-based technique. The anatomy of the occlusion should determine the choice of the initial wire for AWE. To cross a CTO, the wire should pass through the proximal cap, navigate through the body of the occlusion, cross the distal cap, and finally reach the distal true lumen. Understanding the properties of a guidewire is crucial since it is improbable that a single wire will be able to address all the engineering challenges posed by such anatomical heterogeneity. The core, tip, coating, and cover make up the four primary components of a guidewire; even slight changes to these elements have major impacts on the properties of the guidewire.

Guidewires used for AWE can be divided into three main categories: tapered polymer-jacketed wires, intermediate tip-load guidewires, and high-tip-load guidewires. Tapered polymer-jacketed wires are low tip-load wires with tip diameters ranging from 0.008 inch to 0.010 inch. They are used to track tiny and invisible microchannels.

The polymeric cover improves wire lubricity, providing easier navigation through plaque-dense situations where exposed coil wires may struggle. Low weight and a distal polymer sleeve make them less likely to cause vessel exit. As a result, they are often chosen as the primary wire option. Tactile feedback is reduced because of the insulation provided by the polymer jacket; therefore, wire advancement should be guided primarily by fluoroscopic feedback. For this guidewire family, a straight tip advancement is preferred behavior; deflection of the tip must be avoided as it may result in wire entry into the extraplaque space. Sliding is the most effective method for advancing these wires. The procedure entails gently rotating the tip and probing the lesion, allowing the guidewire to locate the path of least resistance, usually through intraplaque microchannels. Examples of wires include the Fielder XT-A or XT-R (Asahi Intecc), Fighter (Boston Scientific), and Bandit (Teleflex).

Intermediate tip-load guidewires encompass a wide range of guidewires, varying in tip load (between 3 and 6 g), tip diameter (0.008–0.014 inch), and the presence of a polymer cover. The characteristics of the lesion dictate the choice of wire Medium gram weight nontapered polymer-jacketed wires are reliable step-up wires (e.g. Gladius EX or MG [Asahi Intecc], Pilot 200 [Abbott], or Raider [Teleflex]), often used to safely navigate an uncertain vessel course, given their low risk of exiting the vessel architecture. The use of non-polymer-coated intermediate tip-load guidewires necessitates an accurate understanding of the vessel's course. These guidewires facilitate active control, penetration, and guidance within the lesion. However, because of their penetration power, they pose an increased risk of perforation. One essential feature of this class of guidewires is steerability.

Drilling is the most effective advancement technique for non-polymer-jacketed intermediate tip-load guidewires. This technique involves controlled, relatively quick rotation movements of the guidewire in both directions by 90°. The guidewire is not forcefully pushed into the occlusion; instead, it maintains steady and engaged contact between the plaque and the wire tip. The deflection and rotation technique is used with Gaia family (Asahi Intecc) guidewires, made possible by their unique and distinctive technology (dual coil and composite core technology). The wire must be advanced in the intended direction when employing this technique. When the tip is seen to be deflected and the wire's body adopts a sinusoidal shape, the wire should be retracted and its tip redirected, enabling controlled advancement of the guidewire and precise navigation through the lesion. A few examples of polymer-jacketed intermediate tip-load guidewire groups are the Raider, Pilot 150/200, and Gladius EX or MG. Non-polymeRr-jacketed intermediate tip-load guidewires include the Gaia family, Judo family (Boston Scientific), and Ultimate Bros 3 (Asahi Intecc).

High-tip-load guidewires are used to penetrate dense and calcified plaques. They often have a tapered tip to enhance penetration force. However, the increased penetration power comes at the cost of decreased tactile feedback. Their use should be restricted to situations where the anatomy is very well defined or when a calcified proximal cap needs to be poked followed by a wire de-escalation.

Penetration is the most effective advancement technique for these guidewires. This technique involves forward guidewire advancement, using the wire as a "needle" to penetrate the occlusion. Examples of wires are Confianza Pro 12 (Asahi Intecc), Hornet 14 (Boston Scientific), Warrior (Teleflex), Infiltrac and Infiltrac Plus (Abbott), or Astato 20 (Asahi Intecc). A complete overview of the characteristics of available guidewires is provided in Table 11.1 [11].

Tips and Tricks

****Searching for the entry point** In a tapered-type entry, the wire is automatically advanced into the appropriate entrance. In contrast, in the abrupt type of entry, it is necessary to look for the dimple sign that is the hallmark of the entry point. At that time, the wire must be manipulated carefully to look for the dimple with the wire-tip trapping pointing toward the small hole of the dimple. When the operator feels/senses the dimple with the wire tip, the operator should maintain that wire-tip position and then rotate the wire-tip 180° to insert the tip inside the CTO [20]. Figure 11.3 Basic maneuvers to control the guidewire.

TOP PERFORMANCE

How to Drill

The shaping of the wire tip should be as little as 1.0 mm in length with an angle of less than 45°, and a second mild curve would be preferable to improve maneuverability of the wire. The wire is rotated to-and-fro with the left hand while the right hand is used for rotating 90–180° and sometimes a full turn (the stored energy must be released by leaving the wire to untorque) with simultaneous moderate pushing and knocking movements.

How to Slide

Sliding is best when engaging microchannels, subtotal occlusions, in-stent occlusion, and angulated segments with careful manipulation (slight rotation, shallow tip curve, very gentle push).

How to Penetrate

During attempted penetration, the rotation movements are smaller (45–90°) and the orientation of the wire-tip position in the operator's mind is crucial for success.

Table 11.1 Task-specific guidewires (reproduced with permission from Dash) [11]

Task	Name	Company	Properties	Coating	Tip load
Access (workhorse)	Sion	Asahi	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic, non-jacketed over spring coil and tip	0.7
	Sion Blue	Asahi	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic, non-jacketed over spring coil (18.5 cm), hydrophobic tip	0.5
	Pilot 50	Abbott	Non-tapered tip 0.014 inch, 190/300 cm	Hydrophilic polymer jacket	1.5
	Whisper MS	Abbott	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic polymer jacket	1.0
	BMW Universal II	Abbott	Non-tapered tip with shaping ribbon 0.014 inch, 190/300 cm	Hydrophilic coating	0.7
	Samurai	Boston Scientific	Non-tapered tip 0.014 inch, 190/300 cm	Hydrophilic, non-jacketed, reduced coating on distal 1 cm	0.5
Microchannel crossing	Fielder XT	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic, full polymer jacket	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180/300 cm	Hydrophilic, polymer jacket	1.0
	Fielder XT-R	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180/300 cm	Hydrophilic, polymer jacket	0.6
	Fighter	Boston Scientific	Tapered tip 0.009 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic, clear polymer jacket over spring coil and tip	1.5
	Bandit	Teleflex Medical	Tapered tip 0.008 inch, shaft 0.014 inch, 200/300 cm	Hydrophilic, polymer jacket	0.8

(*Continued*)

Table 11.1 (Continued)

Task	Name	Company	Properties	Coating	Tip load
Collateral crossing	Fielder FC	Asahi	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic full polymer jacket	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180/300 cm	Hydrophilic, polymer jacket	1.0
	Fielder XT-R	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180/300 cm	Hydrophilic, polymer jacket	0.6
	Suoh	Asahi	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic, non-jacketed over spring and coil tip	0.3
	Sion Black	Asahi	Non-tapered tip 0.014 inch, 190/300 cm	Hydrophilic, full polymer jacket on distal 20 cm	0.8
	Sion	Asahi	Non-tapered tip 0.014 inch, 180/300 cm	Hydrophilic, non-jacketed over spring coil and tip	0.7
	Samurai RC	Boston Scientific	Non-tapered tip 0.014 inch, 190/300 cm	Hydrophilic coating on distal 24 cm	1.2
Knuckling	Fielder XT	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic, full polymer jacketed	0.8
	Fielder XT-A	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180/300 cm	Hydrophilic, polymer jacketed	1.0
	Fighter	Boston Scientific	Tapered tip 0.009 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic, clear polymer jacket over spring coil and tip	1.5
	Pilot 200	Abbott	Non-tapered tip 0.014 inch, 190 and 300 cm	Hydrophilic, polymer jacketed	4.1
	Gladius Mongo	Asahi	Non-tapered tip 0.014 inch, 190 and 300 cm	Hydrophilic, polymer jacketed	3.0

Table 11.1 **(Continued)**

Task	Name	Company	Properties	Coating	Tip load
Navigation	Miracle 3	Asahi	Non-tapered tip 0.014 inch, 180 cm	Hydrophilic (Silicone) Hydrophilic (Silicone)	3.0
	Miracle 6	Asahi	Non-tapered tip 0.014 inch, 180 cm	Hydrophilic coating over spring coil and tip	6.0
	Hornet	Boston Scientific	Tapered tip 0.008 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic, non-jacketed tip	1.0
	Gaia 1	Asahi	Tapered tip 0.010 inch, shaft 0.014 inch, 190 cm	Hydrophilic, non-jacketed tip	1.5
	Gaia 2	Asahi	Tapered tip 0.011 inch, shaft 0.014 inch, 190 cm	40 cm Hydrophilic coating with uncoated distal micro-cone tip	3.5
	Gaia Next 1	Asahi	Tapered tip 0.011 inch, shaft 0.014 inch, 190 cm	40 cm Hydrophilic coating with uncoated distal micro-cone tip	2.0
	Gaia Next 2	Asahi	Tapered tip 0.012 inch, shaft 0.014 inch, 190 cm	Hydrophilic, polymer jacketed	4.0
	Gladius EX	Asahi	Non-tapered tip 0.014 inch, 200 cm	40 cm Hydrophilic coating with uncoated distal tip	3.0
	Ultimatebros 3	Asahi	Non-tapered tip 0.014 inch, 180/300 cm		3.0
Penetration	Gaia 3	Asahi	Tapered tip 0.011 inch, shaft 0.014 inch, 190 cm	Hydrophilic, non-jacketed, tip hydrophilic	4.5
	Gaia Next 3	Asahi	Tapered tip 0.012 inch, shaft 0.014 inch, 190 cm	40 cm Hydrophilic coating with uncoated distal micro-cone tip	6.0
	Gaia Next 4	Asahi	Tapered tip 0.012 inch, shaft 0.014 inch, 190 cm	40 cm Hydrophilic coating with uncoated distal micro-cone tip	10.0
	Miracle 12	Asahi	Non-tapered tip 0.014 inch, 180 cm	Hydrophilic (Silicone)	12.0

(*Continued*)

Table 11.1 **(Continued)**

Task	Name	Company	Properties	Coating	Tip load
	Conquest Pro 9	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 20 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	9.0
	Conquest Pro 12	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 20 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	12.0
	Hornet 10	Boston Scientific	Tapered tip 0.008 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic over spring coil and tip	10.0
	Hornet 14	Boston Scientific	Tapered tip 0.008 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic over spring coil and tip	14.0
	Astato XS 20	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 17 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	20.0
	Astato XS 40	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 17 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	40.0
	Warrior	Teleflex	Tapered tip 0.009 inch, shaft 0.014 inch, 200/300 cm	Distal 20 cm hydrophilic coating	14.0
	Infiltrac 11	Abbott	Tapered tip 0.009 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic coating with micro-textured uncoated tip	11.0
	Infiltrac plus	Abbott	Tapered tip 0.009 inch, shaft 0.014 inch, 190.300 cm	Hydrophilic coating with micro-textured uncoated tip	14.0

Table 11.1 (Continued)

Task	Name	Company	Properties	Coating	Tip load
Fenestration reentry	Conquest Pro 12	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 20 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	12.0
	Hornet 14	Boston Scientific	Tapered tip 0.008 inch, shaft 0.014 inch, 190/300 cm	Hydrophilic over spring coil and tip	14.0
	Astato XS 20	Asahi	Tapered tip 0.009 inch, shaft 0.014 inch, 180 cm shaft, spring coil 17 cm	Hydrophilic non-jacketed over spring coil, hydrophobic tip and shaft	20.0
Externalization	RG 3	Asahi	Non-tapered tip. Tip shaft 0.010 inch	Hydrophilic over spring coil and tip	
	R 350	Teleflex	Non-tapered tip, 0.013 inch shaft, 5 mm platinum coil, 350 cm length	Hydrophilic over spring coil and tip	

ANTEGRADE WIRE ESCALATION

GAME PLAN

The use of a microcatheter is mandatory as it is likely to avoid dissections/extraplaque tracking of the vessel proximal to the CTO while manipulating progressively stiffer wires. This also allows rapid exchange of specialized guidewires during the navigation of the occluded lesion and avoids the need to modify the small distal bend already present in most preshaped dedicated wires. Furthermore, the use of a coil-based structure in the microcatheters (Table 11.2) enables progression within the CTO body, enhancing active support and the penetration power of the guidewire [11].

The first step in AWE is to advance a workhorse wire with the support of a microcatheter to the proximal cap after the CTO analysis using the dual injection is complete. Once the microcatheter is positioned at the proximal cap, a base of operation has been established and will be advanced distally as the procedure progresses. Then an appropriate task-specific wire is chosen based on the anatomical features of the lesion. A low-tip load polymer-jacketed wire such as Fielder XT, Fielder XT-A, Fielder XT-R (Asahi Intec, Japan), or Fighter (Boston Scientific, USA) is a good initial choice for probing the lesion to seek out microchannels. If the cap is tapered, the use of these guidewires provides a high probability of progression by tracking microchannels. During the advancement, it is important to avoid the crossing of bridging collaterals, which are fragile and often extra-adventitial. Since the presence of polymer cover does not give sufficient tactile input, it is imperative to accurately monitor the behavior of the

(*Continued*)

guidewire tip. If the tip bends, giving the impression of encountering a resistant lesion and thus lacking penetration force, it may be reasonable to escalate the tip load. More controllable wires, such as Gaia First and Gaia Second (Asahi Intecc, Japan) can be used early during escalation. A penetration wire, such as Gaia Third, Conquest Pro 12 (Asahi Intecc, Japan) or Hornet 14 (Boston Scientific, USA), Warrior (Teleflex, USA), and Astato 20/40 (Asahi Intecc, Japan) [Table 11.1], is well suited to cross a more fibrous and calcified lesion [11, 19]. In cases of a blunt proximal cap, which typically presents a composition more resistant to penetration compared with tapered caps, skipping the step of using low-tip load tapered polymeric guidewires may still be appropriate given the anticipated low probability of success.

Tips and Tricks

****How to make the tip stronger or stiffer** When the tip of the wire is deviated from the imaginary lumen and the tip does not engage in the intended direction in the proximal occlusive cap, either exchange the wire for a stiffer one or advance a microcatheter close to the tip. The desirable stiffer wires include Confianza Pro 12, Hornet 14, Infiltrac Plus, Warrior, and Astato 20/40 (Figure 11.5).

If the guide disengages with the wire tip pinpointed at the center of the occlusion, either exchange the guide for one with stronger backup or use a microcatheter [15]. The use of a microcatheter (or balloon inflation of the OTW system as a coaxial anchor balloon, i.e. small balloon inflation of the OTW system in front of the proximal cap) is preferable, because the problem is mainly considered to be related to the support of the wire. Specific microcatheters such as the Tornus (Asahi Intecc) or the Turnpike Gold (Teleflex) have a metallic tip and can be used to penetrate and disrupt the proximal heavily calcified CTO cap. Their coiled structure allows them to be “screwed” into the CTO lesion, creating a track through the calcification [21].

****IVUS-guided direct wire entry** The IVUS-guided wiring technique is a useful strategy to detect the entry site of the CTO if the branch is large enough to advance an IVUS catheter (Figure 11.6). First, the IVUS catheter is advanced to the proximal end of the CTO lesion and interrogates the surrounding area. Based on the initial images, the tip of the IVUS catheter may be used to pinpoint the central area of the main lumen at the beginning of the CTO lesion, so the tip of a drilling wire can be positioned here. Then the operator seeks a dimple at the entry with careful wire manipulation. IVUS can be used either through a “live” IVUS-guided puncture or by intermittent serial imaging. During live IVUS-guided puncture, the probe is positioned at the site where the stump can be best viewed, allowing for continuous monitoring of guidewire motion. This facilitates directing the wire through the occlusion cap, ideally targeting its center [22].

In the event of suspected extraplaque position of wire, IVUS may be useful to guide the second wire into the true lumen. This catheter should be advanced into the presumed extraplaque space after 1.5 or 2.0 mm balloon dilatation at the CTO entrance. Then a second stiffer wire should be advanced simultaneously using fluoroscopic and IVUS guidance in parallel. Advancing second wire is oriented to true lumen under IVUS guidance. This process of “crawling forward” should be repeated to advance the IVUS catheter and the second wire alternately. Key points are (1) the ability to translate cross-sectional images of IVUS into three dimensions is required; (2) the second wire should be stiffer, with a tapered tip supported by a microcatheter; therefore, an 8F guide catheter is preferable; (3) the reentry point should be closer to the proximal cap; and (4) contrast injection should be withheld after balloon dilatation in extraplaque space to avoid hydraulic dissection. Multiple overlapping stenting is mandatory to fully cover the enlarged extraplaque space [11, 23].

Table 11.2 **Microcatheters used in CTO PCI**

Name	Catheter length	Distal shaft OD	Proximal shaft OD	Design features	Recommendations
FineCross (Terumo, Japan)	150 cm	1.8 Fr	2.6 Fr	Stainless steel shaft, hydrophilic coating	Very low profile, good deliverability with limited pushability or ability to spin. Good for small and straight CC
Corsair (Asahi, Japan)	135/150 cm	2.6 Fr	2.8 F	Double layer braided stainless steel, kink resistant flexible tip (composed of tungsten powder)	Low profile, easily, deliverable, pushable. Used for traversing and dilating CC. Provides good wire backup and spinning.
TurnPike (Teleflex, USA)	135/150 cm	2.6 Fr	3.1 Fr	Hybrid of braid and a double layer coil encapsulated between two polymer layers (five layers total)	Workhorse catheter that performs well in most CTO cases
TurnPike Spiral (Teleflex, USA)	135/150 cm	2.6 Fr	3.1 Fr	Similar construction	Spiral enhances trackability
TurnPike Gold (Teleflex, USA)	135 cm	3.2 Fr	3.1 Fr	Similar construction	Tip on tip gold enhances forward movement
TurnPike LP (Teleflex, USA)	135/150 cm	2.2 Fr	2.9 Fr	Similar construction with thinner tip braiding for lowering profile	Excellent for very tortuous or epicardial CC
Micro 14 (Roxwood Medical, USA)	155 cm	1.9 Fr	2.5 Fr	Variable pitch braided shaft, torquable	Very low profile for fine and tortuous CC. Micro 14 has extra-supportive tip profile for enhanced pushability.\
Caravel (Asahi, Japan)	135 cm	1.9 Fr	2.6 Fr	ACT-one core precision braided shaft, hydrophilic coating	Low crossing profile, excellent for tortuous CC
Tornus (Asahi, Japan) 2 sizes	135 cm 135 cm	Tapered 2.6 F	2.1 Fr 3.0	Stainless steel braided catheter	Available in 2.1 and 2 Fr. used as support and CC dilator

(*Continued*)

Table 11.2 **(Continued)**

Name	Catheter length	Distal shaft OD	Proximal shaft OD	Design features	Recommendations
Twin pass (Teleflex, USA)	135 cm	2.0 F	2.0 F	DLMC with stainless steel rod shaft with OTW lumen exit port deflection angle 0°	Major side branch near the proximal CTO cap Parallel-wire technique Distal reentry Access of SB at the distal occlusion cap Selective engagement of angulated collaterals, using the reverse wire technique Retrograde crossing and retrograde puncture of the distal CTO cap
Twin pass Torque (Teleflex, USA)	135 cm	2.1 F	2.1 F	DLMC with stainless steel braid shaft with OTW lumen exit port deflection angle 90°	Major side branch near the proximal CTO cap Parallel-wire technique Distal reentry Access of SB at the distal occlusion cap Selective engagement of angulated collaterals, using the reverse wire technique Retrograde crossing and retrograde puncture of the distal CTO cap
Sasuke (Asahi, Japan)	145 cm	1.5 F	2.5/3.3 F	DLMC with 6.5-mm tip to OTW port negates the need for deep engagement in side branches and complex lesions With double stainless steel core, it provides excellent kink resistance and pushability	Same
NHancer Rx (IMDS, The Netherlands)	135 cm	1.5 F	2.3 F	DLMC with 2 distal exit ports for enhanced access of side branches Braid reinforced shaft for improved pushability	Same
ReCross (IMDS, The Netherlands)	140 cm	1.5	2.3/3/3 F	Low profile DLMC with two completely separate over the wire lumens and three distal exit ports	Antegrade dual access, extraplaque guidewire redirection and simultaneous hematoma decompression in the subintimal space and guidewire probing

FineDuo (Terumo, Japan)	140 cm	2.2 F	2.2 F	A hydrophilic coated dual lumen catheter with an OTW lumen and a rapid exchange lumen, with a 1-mm radiopaque marker on the rapid exchange lumen, positioned at a 0.5-mm distance from the distal tip Low profile, tapered flex tip and hydrophilic coating with strong back-up force	Same
Crusade (Kaneka, Japan)	140 cm	1.3 F	3.2 F	A hydrophilic coated dual lumen catheter with an OTW lumen and a rapid exchange lumen, with a 1-mm radiopaque marker on the rapid exchange lumen, positioned at a 0.5-mm distance from the distal tip	Same
SuperCross (Teleflex)	130/150 cm	2.4 F	3.2 F	Dual coil design provides excellent torque response, flexibility, pushability and kink resistance Embedded platinum/tungsten coil provides enhanced visibility along the entire angled tip Angulated Tip 45′, 90′, 90′ XT, and 120′ Hydrophilic coating	Tortuous vessels, angulated side branch rewiring
SwiftNINJA (Merit Medical Systems, USA)	120 cm	2.4 F	2.9 F	A straight tip catheter that articulates up to 180° in opposing directions Hydrophilic-coated distal 80 cm, a braided shaft for pushability, and distal tip deflection ensures successful delivery of the catheter to the desired location	Tortuous vessels, angulated side branch rewiring

CTO, chronic total occlusion; DLMC; dual lumen microcatheter; PCI, percutaneous coronary intervention; LP, low profile; Fr, French gauge; GW, guidewire; OD, outer diameter; CC, collateral channel; OTW, over-the-wire.
Source: From [11] / Korean Society of Interventional Cardiology.

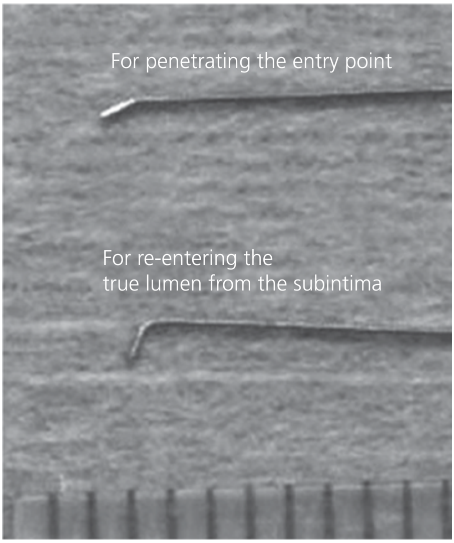

For penetrating the entry point
For re-entering the true lumen from the subintima

Figure 11.5 Typical tip shapes of the tapered-tip wire (Conquest Pro™ or Cross-It™). For the penetrating entry point, its 1.5- to 2.0-mm tip is bent at a curve of about 15–30° (upper panel). For reentering the true lumen from the subintima, an almost 90° bend is required (lower panel).

Large guide catheters are required for this procedure in order to accommodate both the IVUS catheter and a microcatheter at the same time: an 8 Fr should be used with large microcatheters (e.g. Corsair Pro [Asahi Intecc] or Turnpike [Teleflex]), while 7 Fr is enough for smaller microcatheters (e.g. FineCross [Terumo] or Caravel [Asahi Intecc]), using a small profile IVUS probe (e.g. OptiCross [Boston Scientific]) [24].

****Side-branch IVUS guidance** At times, if there is an SB next to the proximal entry of a CTO lesion, an IVUS transducer can be placed in this proximal SB for interrogation of the CTO lesion in the main lumen. If the wire enters a false channel, an IVUS catheter can be advanced there to interrogate the proximal end of the CTO in order to look for a favorable entry location (Figure 11.7). A limitation of this SB technique is the precise anatomical arrangement of an SB. It is possible if the angle of side branch relative to parent vessel and CTO is favorable enough for cross-sectional imaging [11].

DEDICATED EQUIPMENT TO ENTER THE PROXIMAL CTO

E

A unique catheter with special application

In CTO proximal cap at bifurcation, the use of a standard microcatheter may be limited by wire prolapse into the open SB, as a result of either unfavorable angulation or the wire following a lower resistance pathway (where the proximal cap is fibrotic or calcified). Under these circumstances, a dual lumen microcatheter (DLMC) placed on a workhorse wire that is sited distally in the SB provides a stable platform for proximal cap penetration, as the operator can control the wire direction toward the CTO cap better while also augmenting penetration force in this direction. Examples of DLMC include Twin-Pass® (Teleflex Medical, Wayne, PA, USA), FineDuo®/Crusade (Terumo/Kaneka, Tokyo, Japan), NHancer Rx (IMDS), SASUKE® (Asahi Intecc, Aichi, Japan), and ReCross catheter (IMDS, Roden, the Netherlands) [25]. Another catheter that has unique application is the CrossBoss

(Boston Scientific, Natick, MA, USA) catheter for in-stent restenosis of CTOs. Its 1-mm blunt tip prevents it from going behind stent struts. "Fast spin" technology helps to advance the catheter rapidly to the distal cap through the in-stent portion of the CTO [26]. Asia Pacific Chronic Total Occlusion (APCTO) Club has changed original recommendation of using CrossBoss for crossing ISR CTO to using three-dimensional (3D) wiring for ISR CTO [27].

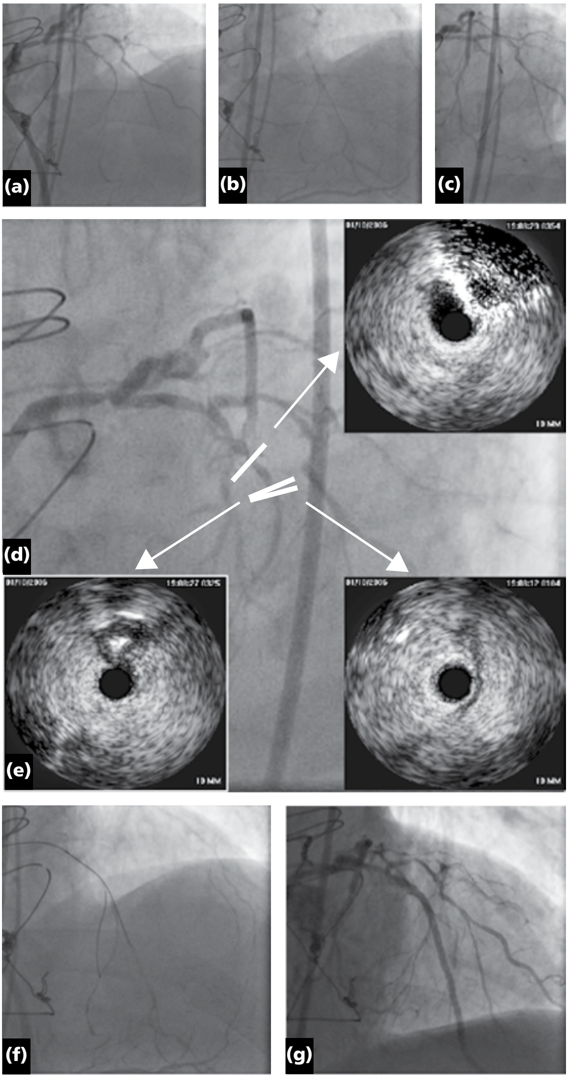


Figure 11.6 Case example with IVUS guidance through the main vessel. (a,b) Although the LAD was completely blocked around its mid-portion, it was hard to identify the entrance of a CTO despite the contralateral injection that was performed. (c) An IVUS catheter was inserted into the septal branch. (d,e) The IVUS easily identified the CTO entrance. (f) This confirmation was also important for use of a stiff wire to penetrate the tight proximal fibrous cap. (g) Final angiographic result after stenting.

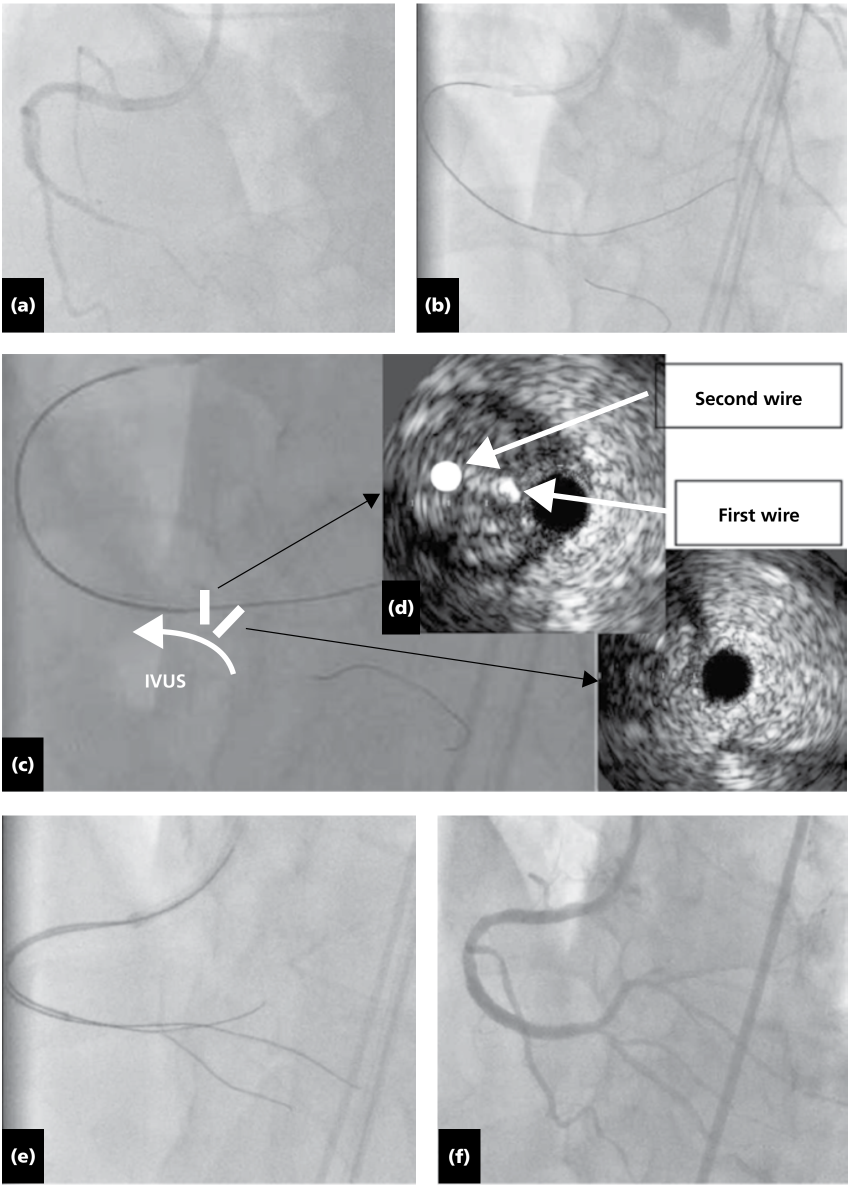


Figure 11.7 Case example with IVUS guidance through the side branch. (a) The first attempt to revascularize the distal RCA CTO failed. (b) In the second attempt, the first wire (intermediate) easily went out of the true channel. (c) An IVUS image from the proximal small branch clearly showed that the entry point of the first wire to the distal RCA was too close to the branch. (d) The wire was easily advanced into the subintimal space. The correct position of the entry point for the second wire is in the center of the obstructed true channel, which indicated the opposite direction to the branch. Therefore, the course of the next wire was intentionally changed from the CTO entrance toward the opposite direction to the branch angiographically. (e) This wire easily entered the distal small branch. (f) Final angiographic result after stenting.

TRAVERSING THE CTO BODY

GAME PLAN

There are three described methods for CTO body crossing: loose tissue tracking, intentional intimal tracking, and intentional extraplaque tracking [28]. The new frontier in CTO body crossing is to use the "anatomy dictates strategy" method and decide up front which method of wiring is to be used [27]. Four approaches have been recommended anatomy: (1) CTOs with tapered stumps or residual channels should be approached with loose tissue tracking and soft tapered tip wires such as XTA, Bandit, or Fighter; (2) CTOs with clear intimal path (i.e. short CTOs, ISR CTOs, and heavily calcified or clear antegrade bridging collaterals that outline the vessel, or CTO with prior patent vessel angiogram) should be approached with intentional intimal tracking and wired with 3D wiring (if fluoroscopic angles allow) using Gaia Next 3 or 4, conquest 12; (3) CTOs without taper stumps and without a clear intimal path should be wired with intentional intimal tracking without 3D wiring using intermediate penetration force blunt tip wires such as UB3, Neo 3, Gladius EX (Asahi Intecc), or Pilot 200 (Abbott Vascular); the Gaia Next 2 (Asahi Intecc) or above wires should not be used if there is ambiguity of vessel course. The intention here is to track intimal path while acknowledging the chance that the wire may move extraplaque; and (4) the "long plus CTOs" with ambiguous course, tortuosity, and heavy calcium should be approached with intentional extraplaque wiring. On balance, if we have a calcified CTO where the intimal plaque path can be seen, knuckle wiring should be preferred in those longer, more tortuous, and more heavily calcified CTOs, whereas shorter, less tortuous ones can be approached with 3D wiring [27].

Tips and Tricks

****Loose tissue tracking** The guidewire advances into the body of the occlusion after the proximal cap has been punctured. If there are no visible calcifications in the lesion, highly penetrating guidewires with a high tip load are rarely required. It is crucial to pay close attention to the position of the guidewire and the microcatheter as it advances through the occlusion; if no progress is made (usually within a few minutes), advancing the microcatheter closer to the wire tip can increase its stiffness; alternatively, switching the wire can be done without losing the acquired position.

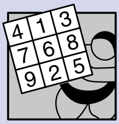
Previously, the "loose tissue tracking wires" such as XTA wire, fighter, or Bandit have been used for loose tissue tracking [28], and they remain a good option for many cases. However, the Gladius EX wire, a polymer jacketed 3-g tip load nontapered wire can also perform loose tissue tracking when a little more penetration force is needed and is often a better first-choice wire for loose tissue tracking [27].

****Intentional intimal tracking** When there is a clear fluoroscopic path indicating the intimal position, intentional intimal tracking is feasible but requires precise knowledge of the intimal position, for instance, in severely calcified CTO or ISR CTO, where the calcium outlines the location of the intimal plaque or the previous angiography prior to coronary occlusion. It is also possible to clearly locate the intimal position and enable intentional intimal tracking by inserting an IVUS catheter into the extraplaque space. In theory, if MSCT can be of high enough resolution and be correlated to the angiographic views with an accurate software, MSCT-correlated intentional intimal tracking can be done in the future [27]. Intentional intimal tracking is currently only useful in ISR, previous angiogram of patent vessel, short clear-course CTOs, and severely calcified arteries. There has been a shift toward 3D wiring in recent years due to the development of wires that can precisely deliver a degree of torque to the tip, such as the Gaia next series. Although we are processing data from a 2-D fluoroscopic output, it is clear that the wire inside a coronary artery is a 3D object inside a 3D structure. Nonetheless, it is feasible to reconstruct a 3D image by using appropriate angles, enabling 3D wiring. After initially describing a 3D method, Okamura et al. [29] later demonstrated that the technique was safer, faster, and more effective when applied to retrospective registry data [30]. The group came up with the "same in front, opposite behind" principle at the same time [30]. Even in situations when the wire has gone extraplaque, others have successfully replicated this technique [31]. However, due to the challenges of comprehending the ideas and creating a mental 3D vision, 3D wiring has not been widely adopted worldwide. The essence of 3D wiring has recently been condensed into 10 tips by Wu, Nagamatsu, and Okamura [32], which can help an operator reap the majority of the benefits of 3D wiring without actually creating a mental image or performing 3D wiring. Additionally, the APCTO Club has created ADAPT, a 3D wiring approach that eliminates the requirement for mental image. These methods can also be applied to intentional intimal tracking [27].

It is imperative to emphasize that the guidewire should always be positioned properly before moving the microcatheter forward because there is a chance that the risk of pushing it outside the vascular architecture could lead to severe consequences. Most of the time, there are no serious consequences from a guidewire-induced perforation. However, if a microcatheter or other equipment causes the same problem, the situation is very different. Guidewire position can be monitored through contralateral injection (two orthogonal views are needed) or fluoroscopic visualization of the vessel profile, in cases of extensive calcifications or intra-stent lesions. The guidewire should exhibit a synchronous "dancing" movement with the vessel. Antegrade injection is not advised due to the possibility of propagating any dissection flaps created by wiring attempts; additionally, antegrade visualization may be compromised due to wire-induced damage to bridging collaterals or microchannels; and in the event that ipsilateral collaterals are present, a second microcatheter positioned in a donor branch for selective contrast injection may be used, offering a valid method of distal visualization without requiring direct injection from the guiding catheter [22].

GAME PLAN

De-escalation of the Wires



If stiff guidewires were required for puncturing the proximal cap or crossing resistant segments within the occlusion, it is advisable to switch to softer guidewires as soon as possible to reduce the risk of perforation. The characteristics and proprieties of the guidewires during AWE must be adjusted throughout the entire procedure based on the type of tissue to cross, with a stepwise process of escalation or de-escalation of their penetration power. The ultimate goal is always to effectively and efficiently reach the distality of the vessel while ensuring safety.

SHARP THINKING

Where are the Sign Posts?

Lesion calcification or occluded stents serve as guideposts of the vessel course [4]. The presence of a tapering distal portion and chronic buildup of jagged hard plaque around the true lumen can make it extremely difficult for the wire to penetrate the distal cap of the CTO. Another important piece of information given by the collaterals is where the collaterals enter the arterial segment beyond the proximal cap: at its distal or mid-segment. The suspicion is that if there is any plaque or stenosis at the distal end, then the collaterals would enter the artery at the middle of the CTO segment [4].

Tips and Tricks

****Where is the wire?** Important feelings that should be focused on during PCI include:

1. **The feeling of the dimple** at the entry point, especially in the abrupt type of CTO entry, is the key to success, but the dimple does not always guarantee intimal plaque tracking.
2. **The feeling of strong resistance** when pulling back the wire inside the CTO body, such as when the guide is drawn into it. In this situation, the wire tip has most likely migrated into the subintima. Free movement of the wire tip during rotation and resistance to advance is a marker of subadventitial position (the wire turns around the vessel lumen giving the appearance of lengthening the tip curve).
3. **The feeling of no resistance**. The wire tip moves freely. This most likely means that the wire tip is either in the true lumen or in the extravascular space.

****How to avoid extraplaque entry?** When trying to cross a curved segment, avoid positioning the wire at the inner curve of the bend. The reason for this is that the original lesion usually starts at the inner border of the curved segment. If the wire goes extraplaque on a straight portion then there are hard plaques inside the CTO that deflect the wire. If a false channel has been created, pull the wire back to the point proximal to the entry of the false channel and find a different new channel to go down [4].

Extraplaque guidewire position If the antegrade wire ends up in the extraplaque space, this does not imply that the AWE strategy has failed or that a different approach is needed. The techniques to address these scenarios are: wire redirection, whereby the guidewire is retracted and redirected (performed with a steerable guidewire such as the Gaia and Gaia Next); parallel wire technique; and ADR or retrograde approach.

Parallel wire method Once the wire enters extraplaque position, it is left as such to seal the tract and act as a marker. Continued advancement of this wire close to the distal cap should be avoided as it may prevent expansion of extraplaque space and collapse the distal true lumen and make the entry into the true lumen more challenging. The parallel wire technique is leaving the tapered tip low or medium strength wire in extraplaque space while introducing a second wire in parallel that is stiffer penetration wire. This second wire is then attempted to navigate in the true lumen of the vessel (Figure 11.8).

The key concept of this technique is to close the entry point to the extraplaque space with the first wire, preventing the second one from tracking the wrong pathway and enhancing the possibility of following a new route through the intraplaque space. Usually, in this technique, the microcatheter is removed from the first wire and reused during the new attempt. The parallel wire strategy with two microcatheters at a time is called "seesaw wiring" where the operator is able to move either of the two wires at a time. It has the advantage of avoiding the need for complex exchange of microcatheters. Wires can be reshaped and their roles switched promptly (Figure 11.9). A contemporary modification of this historical technique is DLMC-facilitated parallel wire technique with one monorail port and a second OTW. The catheter is introduced along the monorail port on the extraplaque wire and advanced until the entry point of the extraplaque space. Next, the penetrating wire is introduced through the OTW port for parallel wiring as described earlier. This catheter allows the introduction of multiple wires while maintaining an ideal base of operation position without the requirement for a second microcatheter [11].

The modified microinjection This technique involves the injection of a small volume of contrast (<1 mL) through a microcatheter or OTW balloon. A microcatheter is preferable due to the radio-opaque marker at the catheter tip (as opposed to in the middle of most currently available OTW balloons) and its lower profile. The microinjection technique involves a gentler injection of a small volume of contrast [33] (Figure 11.10a).

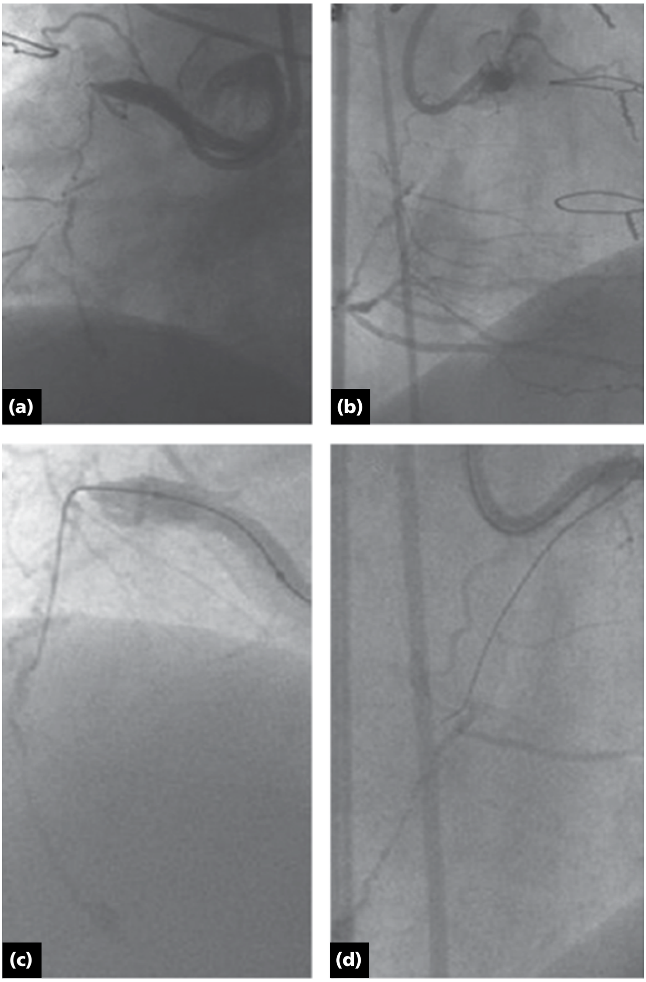


Figure 11.8 (a,b) CTO lesion with a bridging collateral in proximal RCA, shown in LAO and RAO views before intervention with seesaw wiring technique. (c,d) Parallel wire method of seesaw wiring. (c) LAO view and (d) RAO view show that the wire is deviated from the true lumen, a little to the right in (c) and to the left in (d). Leaving the first wire in place as a landmark, a second wire is advanced and directed into the true lumen. (e–f) The second wire is viewed at the left and right of the first wire, respectively, in (e) LAO view and (f) RAO view. (g) LAO view and (h) RAO view show post-stenting angiograms.

Engineering explanation The rationale behind the minimal amount of contrast and reduced injection force relates to the generation of hydraulic forces in a forward direction along the longitudinal axis of the involved vessel. If hydraulic forces are applied through a solid occlusion by a selective injection of a small volume of contrast, the contrast will follow the path of least resistance, represented by the loose tissue segments within the occlusion. If the amount of contrast or the injection pressure is increased, the presence of high-resistance intra-occlusional areas (fibro-calcific plaques) will divert hydraulic forces in a radial direction to the extraplaque space, which is usually softer than the intraluminal obstructing material. In fact, excessive force may lead to contrast extravasation [34].

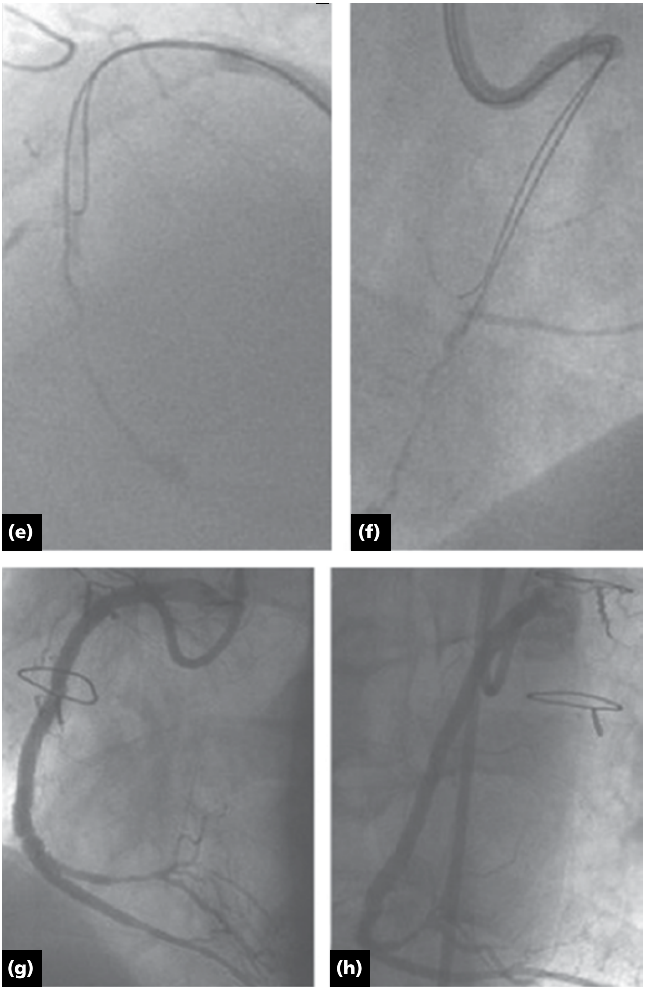


Figure 11.8 (Continued)

The purpose of the microinjection is to modify the compliance of the plaque by softening the loose tissue of the occluded segment through an injection of viscous liquid (in this case, contrast). This technique may facilitate CTO crossing with a dedicated coronary wire or enable access to the subintima, thereby facilitating a dedicated reentry procedure.

An additional application of this maneuver is to identify the exact position of the distal tip of the wire/microcatheter and its relationship to the target vessel architecture. An injection in the extraplaque space resulting in a tubular dissection (Figure 11.10a) would indicate a location within the architecture of the main vessel and provide a road map to aid in further wire manipulation. A storm cloud appearance (Figure 11.10b), in contrast, would indicate that the catheter tip is in a small branch. This appearance will thus guidewire redirection and correct placement of the wire in the architecture of the main vessel, allowing the safe continuation of the procedure [34].

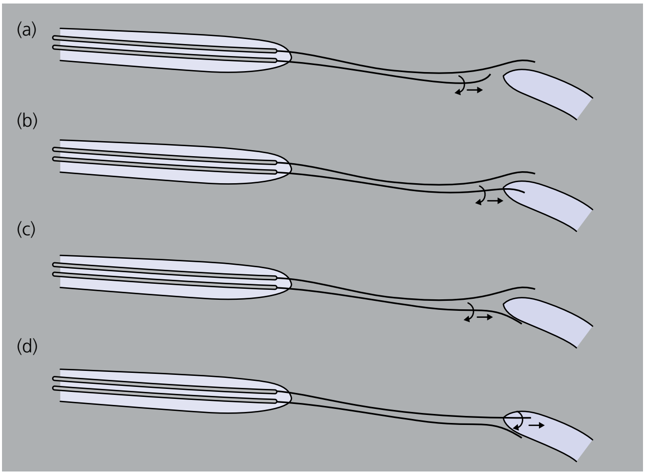


Figure 11.9 Seesaw wiring (parallel wire method with two support catheters). (a) When the first wire fails to cross into the distal true lumen, the first wire is left as a landmark and the second wire is advanced into the occlusion site using the second support catheter. (b) The second wire is successfully manipulated into the true lumen. (c) Alternatively, the second wire fails to enter the true lumen. (d) Use of two support catheters facilitates role-exchange of the two wires. The first wire now is successfully engaged in the true lumen.

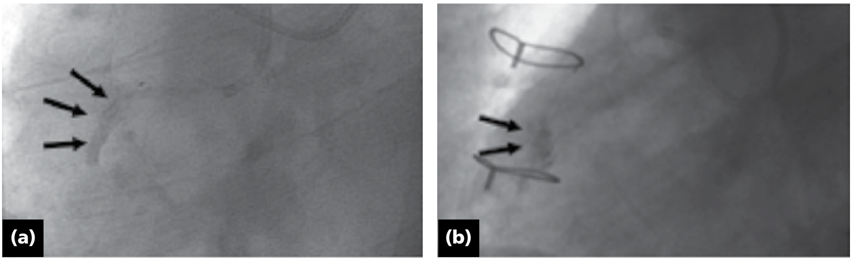


Figure 11.10 The microinjection technique. (a) Appearance of tubular dissection (arrows, indicating position within architecture of vessel) following microinjection through the tip of the OTW balloon. (b) Appearance of storm cloud (arrows, indicating position of the tip in a small branch following microinjection [18]. Reproduced with permission of Wiley.

DISTAL CAP PUNCTURE INTO THE DISTAL TRUE LUMEN

One of the important frontiers in AW for distal cap puncture is the recognition of the dangers of losing an SB in CTOs with the distal cap at a bifurcation. It has been recommended to adopt retrograde approach in CTOs where the distal cap is located at a bifurcation and there is a feasible retrograde option. The APCTO Club acknowledges that not all distal caps are the same and certain features strongly a tough distal cap that requires a step to a high penetration force wire for successful wiring [26]. These include the rounded distal cap stump, the presence of a large SB at the distal cap, visible calcium at the distal cap, and sharp tapered distal cap stump. Now, APCTO club further proposes that if a tough distal cap is seen, it is recommended to use 3D wiring techniques for distal cap puncture with a high penetration force wire because it would be safer and faster [29].

Tips and Tricks

**** Angiographic 3D antegrade puncture technique** The 3D wiring technique recommended by the APCTO Club is the angiographic 3D antegrade puncture technique (ADAPT). Following are the 10 steps to successful distal true lumen wiring [32]:

1. **Stop when the antegrade wire reaches 10 mm proximal to distal cap:** Wires require longitudinal distance to change direction and wires perform better when wiring through virgin territory. Therefore, operators should stop 10 mm before they reach the distal cap to allow adequate longitudinal distance for the wire to be directed in virgin territory toward the distal cap.
2. **Advance the microcatheter toward the wire tip and consider increasing the penetration force:** As backup force and penetration power are both essential for wire control, navigating the microcatheter (using a small balloon to break the proximal cap if the microcatheter cannot be advanced) and increasing penetration force is essential for wire control. It is recommended to use the penetration force of a Gaia Next 3 or 4 or a Conquest Pro 12g wire. The wire should be shaped with a Gaia Next-like tip bend of 45° at 1 mm, and a further 15° bend at 7 mm. A high penetration force wire is safe if the wire tip is already 10 mm from the distal cap, as there will be no ambiguity in vessel course.
3. **Recognize the tough distal cap anatomy:** Four patterns of distal cap predict a "tough" cap anatomy: (1) a tapering cap, (2) a calcified cap, (3) a blunt round cap, and (4) a cap with a large SB. It is advisable to step up to at least a Conquest 12g wire when we see a tough distal cap (or a higher penetration force wire such as a Hornet 14, a Conquest 8/20, or a Conquest CPST.
4. **Put a torque device on the wire:** A torque device allows for small degree angle rotation of the wire, which is needed for the secondary rotation.
5. **Take a cineangiogram with retrograde injection in biplane orthogonal views 90° apart with specific angles to the distal cap location.** Retrograde injection is standard practice for CTO PCI. Fluoroscopic views 90° apart allow the use of 3D information for wiring and are far superior to lesser angles. The specific views for common distal cap locations are left anterior oblique (LAO) 45 and right anterior oblique (RAO) 45 for the mid-RCA mRCA; LAO 45 cranial 30 and RAO 45 cranial 30 for the mid-distal (d) LAD artery; and LAO 30 cranial 45 and LAO 30 cauda 45 for the dRCA. For the dRCA, it is necessary to use a single plane and rotate from cranial to caudal. The full description of fluoroscopic angles for all coronary segments has been published previously [32].
6. **In the far view, turn the wire toward the target.** The far view is the view where the wire is further from the distal cap. First choose the far view where the wire is further from the target and then rotate the wire tip to point toward the target. This is the primary rotation.
7. **In the near view, turn the wire toward the target with small rotation only.** The near view is the angiographic view where the wire is nearer to the distal cap. In this view, where the wire is nearer to the target, rotate the wire slightly toward the target, never more than 40°, and not until the wire faces directly toward the target. This is the secondary rotation. The near view is foreshortened and has significant parallax error; therefore, always rotate less than what appears visually correct.
8. **Return to the far view to wire the distal cap.** Although it may seem easier for the operator to wire using the near view, it is always better to wire using the far view due to overlap in the near view.
9. **For a near-side miss, pull back the wire further and try again.** The wire can miss the target either by going near-side to the target or the far side, overshooting the target. In the case of a near-side miss, pull the wire and microcatheter back further so that the wire tip is 15 mm proximal to the distal cap, thus allowing the wire a longer distance to travel across toward the target.

10. **For a far-side overshoot miss, pull back the wire to the center of the distal cap, rotate it 180°, and try to puncture again.** Since we have used two 90°-apart views, our wire direction should be very accurate and, therefore, if we overshoot the target, a 180° rotation will realign our wire direction toward the distal cap. Therefore, for a far-side miss, we should pull the wire back until the wire tip is just proximal to the target, rotate it 180°, and reattempt the puncture into the distal true lumen.

*****How to confirm that the wire is in the true distal lumen** Once the wire enters the distal lumen, its tip should show easy free movement and smooth retraction or advancement.

There are five methods to verify the true lumen position. A contralateral injection is the most favored approach because it allows confirmation without the need for additional instrumentation or equipment advancement. Other techniques include contrast injection, IVUS, or microcatheter pressure transduction; however, these may portend some risk given the need to inject contrast or advance catheters through the occlusion. Another novel method to confirm the distal true lumen position during PCI is an intracoronary Doppler guidewire [35].

IN-STENT-RESTENOSIS CTO

ISR CTO PCI represents 15% of all CTO interventions. Four patterns of ISR CTO include pattern A: CTO within the stent segment; pattern B: CTO beyond the distal edge; pattern C: CTO beyond the proximal edge; and pattern D: CTO beyond both the proximal and distal edges [36].

There are excellent initial outcomes of PCI for CTO within the stent segments (pattern A), with a high technical success rate. Several reasons for the excellent initial outcomes have been proposed. (1) As the proximal cap and the distal exit of the CTO lesion are positioned within the previously implanted stent, a guidewire can be navigated easily from the proximal cap into the intimal plaque of the CTO body, and from the distal exit into the distal true lumen in AWE technique. (2) The previously implanted stent acts as a road map for the target vessel, due to the newly developed coronary angiogram equipment, as well as the visible materials used in recent coronary stents. (3) The development of innovative, such as guidewires and microcatheters, makes it possible to perform AWE in ISR CTO that can be visualized with the previously implanted stent. PCI for CTO beyond the proximal edge (pattern C) has a longer procedural time and longer fluoroscopic time than for CTOs within the stent segment (pattern A). However, there is no significant difference in the technical success rates between these two patterns. PCI for CTO beyond the distal edge (pattern B) shows a lower technical success rate, longer guidewire crossing time, longer procedural time, longer fluoroscopic time, and a higher contrast volume than CTO within the stent segment (pattern A). With regard to CTO beyond both the proximal and distal edges (pattern D), the technical success rate is lower than that of the overall CTO-PCIs guidewire crossing through a CTO beyond both the proximal and distal edges presents unique limitations. Indeed, the retrograde approach is required in case of a guidewire failure in the antegrade intentional intimal plaque tracking at the transition from the proximal cap to the proximal stent segment, or from the distal stent segment to the distal exit [36].

Tips and Tricks

****Crossing of in-stent CTO body** ADAPT can be used as a 3D wiring method for intentional intimal tracking in ISR CTO [32]. This new method provides a five-step simple and learnable method for easy 3D wiring: (1) set up identical to the first four steps of ADAPT wiring, with wiring only 5–10 mm with each step, using high penetration force wires, keeping the microcatheter support strong, and using 90° apart specific fluoroscopic angles for particular coronary segments; (2) identify the far view and rotate the wire tip toward the target – which is defined as the center of the vessel; (3) go to the near view and straighten the wire tip, which will let us know which direction will rotate the wire tip toward the center of the vessel; (4) in the near view, rotate the wire tip until it just begins to move toward the target and then push forward observing the wire in the far view; and (5) stop when the wire tip gets to the center of the vessel in the far view or has traveled 5 mm and reassess again.

BALLOON ANGIOPLASTY

Once a wire has crossed into the distal true lumen, the microcatheter should be advanced beyond the distal cap and the wire exchanged for a workhorse wire. After the occlusion has been crossed and dilated with the balloon, the true dimensions of the CTO may be appreciated and subsequent angioplasty and stenting performed with appropriate-sized devices. It should be noted that chronic low-flow spasm in the distal vessel is common after CTO recanalization, so often large and repeated doses of intracoronary nitroglycerin or other vasodilators are needed for the true reference vessel diameter not to be underestimated.

Tips and Tricks

****Crossing a balloon uncrossable CTO** Uncrossable lesions are those that cannot be crossed with a balloon after successful guidewire crossing, often due to heavy calcification, tortuosity, or a combination of both [37]. The strategies that may be considered for such difficult situations include:

First-line strategies **Guide Catheter Support:** Adequate guide catheter support is crucial for the success of PCI in uncrossable lesions. Catheters provide either passive support, determined by the catheter's size, shape, and stiffness, or active support, which requires manipulation for deeper engagement. Passive-support catheters include the Voda, EBU, and XB catheters, while active support can be enhanced by specific techniques, such as the "power position" with an Ikari left catheter.

A. Supportive shape selection: Use Voda, EBU, or XB catheters for left coronary arteries, and AL for the RCA. Ikari left can be used for either artery with the "power position" technique.
B. Larger diameter: A larger French (Fr) size provides greater passive support.
C. Longer sheaths: These enhance guide stiffness and bypass arterial tortuosity, allowing better manipulation and torque transmission.
D. Deep intubation: The guide catheter can be advanced temporarily using slight rotations to help device delivery through tight lesions.
E. Power positioning: For catheters like Ikari left or Judkins left, push until the secondary curve sits in the aortic sinus for better support, avoiding ostial or proximal lesions.
F. Buddy wiring: Stabilize the guide by using a second wire to either straighten the vessel or anchor it for additional support.
G. Guide extensions: These extend the guide's length to assist with deep coronary engagement or across tortuous segments.

1. **Balloon selection**
   For lesion preparation, using noncompliant (NC) balloons sized 1:1 to the vessel diameter is essential. However, semi-compliant, low-profile balloons (0.85–1.5 mm) with lubricious coatings should be used first – such Sapphire Pro, Mini-Trek, Nano, Across CTO, Apex Push, Blimp (new ultralow profile balloon), and Chocolate balloons – to facilitate larger balloon crossing. Repetitive forward and backward oscillation of the balloon may help reduce resistance, capitalizing the physical principle that dynamic friction is less than static friction and may help with crossing the balloon uncrossable lesions (balloon-wedge technique) (Figure 11.11).
2. **Wire-based Support Techniques**
   Supportive wires, such as the Wiggle wire (with several bends proximal to the tip), help redirect pushing forces to navigate the gear. Techniques like the buddy wire (technique involves a second wire to enhance support, straighten tortuous bends, and reduce wire bias) or wire cutting can also improve success in crossing uncrossable lesions [37]. The wire-cutting procedure involves positioning and inflating a balloon over the first guidewire while advancing a second guidewire through the occlusion. The proximal cap is then cut and

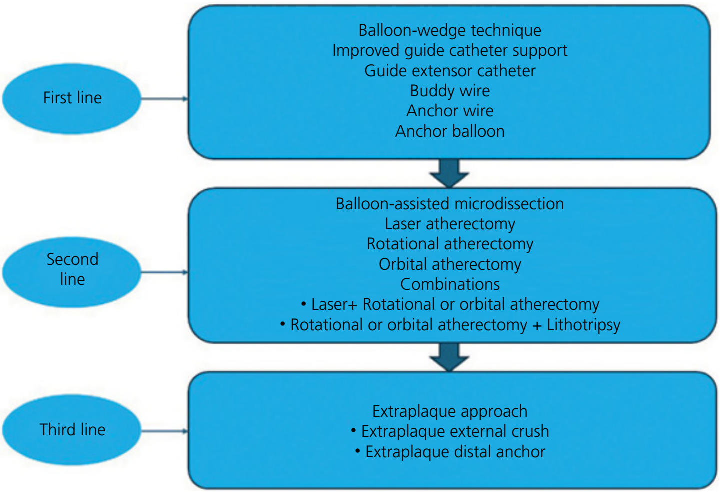

First line
Balloon-wedge technique
Improved guide catheter support
Guide extensor catheter
Buddy wire
Anchor wire
Anchor balloon
Second line
Balloon-assisted microdissection
Laser atherectomy
Rotational atherectomy
Orbital atherectomy
Combinations
• Laser+ Rotational or orbital atherectomy
• Rotational or orbital atherectomy + Lithotripsy
Third line
Extraplaque approach
• Extraplaque external crush
• Extraplaque distal anchor

Figure 11.11 An algorithmic approach to balloon uncrossable chronic total occlusion. (techniques can be used in isolation or in combination).

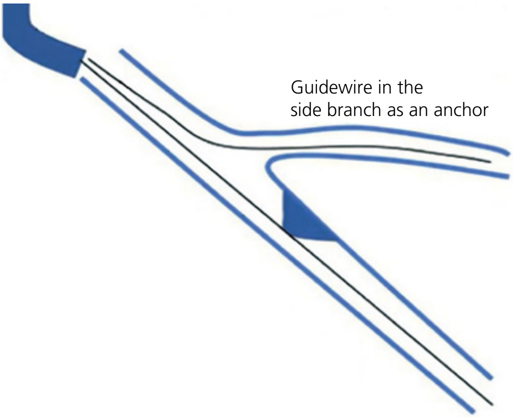

Guidewire in the
side branch as an anchor

Figure 11.12 Schematic illustration of side branch anchor wire technique.

modified when the second guidewire is removed, while the balloon is still inflated. A fresh balloon is advanced upon deflation and removal, and it frequently passes through the altered lesion (Figure 11.12).

3. **Anchoring Techniques**
   Anchor balloons provide additional stability. In the SB anchor technique (Figure 11.13), a guidewire is advanced into an SB, such as the conus or acute marginal branch for the RCA, or the diagonal branch for the LAD artery. A small balloon, typically 1.5–2.0 mm in diameter depending on the size of the SB, is then inflated at 6–8 atm. This anchors the guide into the vessel, facilitating the advancement of balloons or microcatheters [37]. To enhance support further, guide extension anchoring technique (Figure 11.14) can be used but a second guide catheter will be needed to advance a balloon beside the guide extension, the balloon is then inflated against the trap guide extension which subsequently increases the support and enhances equipment delivery.

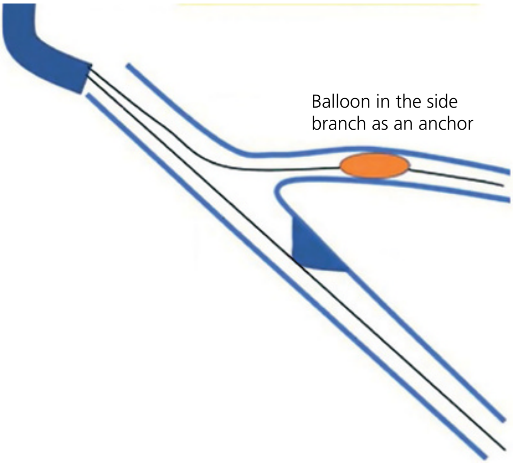


Figure 11.13 Schematic illustration of side branch anchor balloon technique.

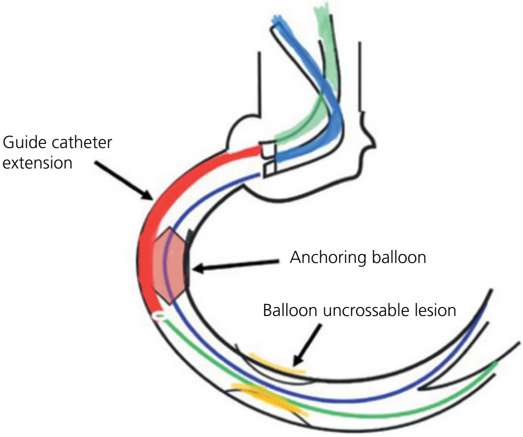


Figure 11.14 Schematic illustration of the guide extension anchoring technique.

4. **Microcatheters**
   By enhancing pushability and permitting wire exchanges, microcatheters like the Tornus (Asahi Intecc, Japan) or Turnpike Spiral (Teleflex, USA) aid in lesion crossing. For instance, the Tornus' metal coil design increases torque transmission, while the Turnpike Spiral's rotational assistance aids in navigating resistant lesions [37].

Second-line strategies

1. **Balloon-assisted microdissection**
   Balloon-assisted microdissection involves the use of a low-profile balloon advanced and inflated at high pressure with deliberate intention to rupture at the beginning of the lesion to create microdissections within the proximal cap, facilitating subsequent passage of the balloon [38]. It is crucial to remember that this technique may result in complications like dissection and perforation. Furthermore, there can be times when it is difficult to remove the ruptured balloon.

2. **Excimer laser coronary atherectomy**
   Excimer laser coronary atherectomy (ELCA) uses monochromatic ultraviolet light to ablate calcified tissue via photochemical, photothermal, and photokinetic mechanisms. This technique is particularly useful for modifying heavily calcified lesions, allowing subsequent balloon passage. ELCA is a good approach for addressing balloon uncrossable CTOs because the interventionists can use any 0.014-inch guidewire, in contrast to orbital and rotational atherectomy (RA). As a combination technique, laser can be used to facilitate a microcatheter to cross the lesion, which can then be exchanged for an atherectomy wire, followed by rotational or orbital atherectomy (OA) for plaque modification before ballooning and stenting.
3. **Rotational atherectomy**
   One effective therapy against a balloon uncrossable CTOs is RA. The requirement for switching it out for a 0.009-inch rotawire is its Achilles heel. Sometimes the balloon-uncrossable lesion prevents this exchange. Sometimes the microcatheter tip can be “buried” into the lesion and wired straight into the distal lumen with the rotawire when all other options have failed. It is essential that the RA burr be advanced repeatedly and gently to avoid “wedging” it into the lesion with force [39]. The ROTABLATOR system and ROTAPRO (Boston Scientific, USA) offer burr diameters ranging from 1.25 to 2.50 mm for differential ablation of calcific tissue.
4. **Orbital atherectomy**
   A further technique for overcoming balloon uncrossable CTOs is OA. By using DiamondBack 360 system, OA creates a “sandblasting” action that disintegrates the calcified tissue into microparticles, which are then absorbed by the bloodstream. Even after RA and other techniques have failed, OA has demonstrated efficacy. A novel area of CTO PCI is the potential to use OA to treat fibrotic or extremely refractory occlusions [38].

Third-line strategies **Dissection reentry (Extraplaque approach)** In extreme cases where all other methods fail, operators may resort to the extraplaque dissection reentry technique. This involves creating a dissection plane around the occlusion and reentering the true lumen on the distal side of the lesion (Figure 11.11).

IN-STENT CTO

SHARP THINKING

Change of Tactics

ADR becomes a valuable bailout option when AWE fails to reach the distal true lumen and acquires an extraplaque situation. ADR can also be used as a first-line strategy in case of long (>20 mm) occlusions with an ambiguous or impenetrable proximal cap or, again, in case of an ambiguous or tortuous vessel course (Figure 11.1) [11].

ANTEGRADE DISSECTION REENTRY

GAME PLAN

The strategy is to traverse the occluded segment within the extraplaque space with subsequent distal reentry back into the true lumen. Dissection may be inadvertent by advancing a wire in the extraplaque space or intentional by knuckling a polymer-jacketed wire. The wire is navigated against resistance until it folds back on itself to form a knuckle (or the tip is purposefully shaped by the operator into a “J” shape). Wire selection varies, usually involving specialized guidewires like the Gladius Mongo (Asahi Intecc, Japan), which has an abrupt core tapering 8 mm from its tip (a "knuckle point") or low-tip load polymer-jacketed, such as the Fielder XT family (Asahi Intecc, Japan). In contrast, larger knuckles are typically produced by the higher tip load polymer-jacketed guidewires, such as Pilot 200 (Abbott Vascular, USA), Gladius (Asahi Intecc, Japan), and Raider (Teleflex, USA). Although smaller knuckles (e.g. Gladius Mongo) are generally suitable for both dissection and reentry, larger knuckles may be preferred during the dissection phase, in cases where avoiding SB is crucial (e.g. acute marginal branches in the RCA) or where a higher tip load is instrumental in overcoming fibrocalcified tissue. Despite the fact that knuckling is widely regarded as safe, care should be taken emphasizing stepwise progress and vigilant tracking in orthogonal projections to ensure proper knuckle propagation along the anticipated trajectory of the main vessel, and avoiding deep advancement into smaller branches. It is critical to avoid antegrade injections to prevent hydraulic extension of the dissection plane. Furthermore, care should be taken with wire tip control as any movement of the wire within the extraplaque space may come at the cost of expanding intramural hematoma.

Ever since the introduction of ADR, reentry in the true lumen has been the holy grail of PCI for CTO. It is still the subject of extensive scientific and technological research efforts. Reentry can be accomplished through various methods, which fall into two categories: device-based and wire-based (with or without intravascular imaging guidance) [11].

Once in the extraplaque space, advanced CTO PCI dissection reentry techniques are required for distal reentry into the true lumen and may not always be possible. There is a risk of perforation if the wire and/or the microcatheter exit the vessel architecture [32].

SHARP THINKING

Keys for Success

The first key required for success is precise control of the wire and microcatheter when entering the extraplaque space in order to prevent prolapse. This precise control can be technically challenging. Prior to microcatheter advancement, knowledge of wire position is paramount and can only be gained through experience. The second key for success is not to expand the antegrade dissection plane proximal to the CTO segment. This can compromise distal visualization due to the formation of a proximal compressive hematoma.

The third key for success is to limit the loop size of the knuckle wire and not inject contrast through the antegrade guide once the dissection has been created. The fourth and most important key for success is good visualization of the Stingray balloon after it is prepped so that its orientation in the vessel is such that the offset ports can be seen as a single line in profile and a clear path to the true lumen is identified. Overall, the ADR technique requires familiarity with extraplaque entry and management along with an understanding of the required tools and their properties.

Subintimal Tracking and Reentry

Subintimal tracking and reentry (STAR) involves advancement of a looped or "knuckled" guidewire into a dissection plane (Figure 11.15) until it reenters the distal true lumen [40]. This technique has very high rates of restenosis on short-term follow-up due to extensive dissection planes, loss of significant SB, and poor run-off. A modification of the STAR technique called the contrast-guided STAR [41] consists of extraplaque contrast injection through a microcatheter positioned at the proximal cap to create/visualize a dissection plane and guide the wire advancement employing the "microchannel technique"[33].

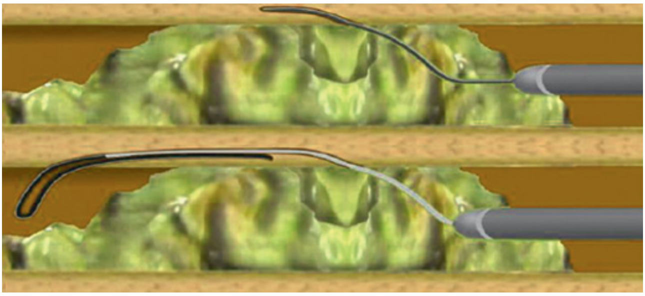


Figure 11.15 Schematic illustration of subintimal tracking and reentry by use of knuckle wire.

The mini-STAR technique [42] is used when an attempt is made to wire the occlusion as far as possible before entering a dissection plane,[22] that minimizes the length of extraplaque wire passage. A small first curve (40°–50°) at the distal end (1–2 mm proximal to the tip) and a second curve (15°–20°) 3 to 5 mm proximal to the tip are placed on the wire in the mini-STAR technique. This is in contrast to the STAR and contrast guided-STAR techniques, in which an umbrella handle wire configuration is made before insertion through the microcatheter. The wire is advanced toward the CTO resulting either in distal true lumen crossing or the wire forms a J-loop that is advanced for extraplaque penetration of the CTO, followed by efforts to reenter the true lumen as proximally as possible limiting the length of the dissection plane. These modified techniques do not overcome the pitfall of STAR: that reentry cannot be controlled. These techniques have poor medium- and long-term outcomes [43–44]. STAR currently only serves as last bailout strategy in case of impending failure, with the goal of performing an investment procedure. Patients are typically brought back approximately 6–8 weeks later for a staged reattempt, allowing the dissection planes to heal before further PCI. This deferred stenting strategy has been associated with improved patency rates on follow-up [45].

Another technique in the context of wire-based ADR is limited antegrade subintimal tracking (LAST); the primary goal of which is to achieve a wire-based reentry as close as possible to the distal cap by using a high-tip-load and torqueable guidewire with a sharp bend at its tip [46]. However, the LAST technique remains less predictable and reproducible, with lower technical success than the device-based techniques [47].

An IVUS interrogation is incorporated into a modified version of the LAST procedure to facilitate reentry. One 8F guide catheter or two guide catheters (dual-guide method or ping pong) are used to accomplish this [48]. Very recently, a first-in-man case with a novel optical coherence tomography-guided CTO reentry device was reported, real-time high-resolution visualization with graphical augmentation, thus allowing precision steering and advancement of a guidewire [49].

How to Perform Antegrade Fenestration and Reentry?

Antegrade fenestration and reentry (AFR) is a novel nontargeted ADR technique. It consists of creating multiple fenestrations of the dissection flap separating the false and true lumen. In this technique, a balloon sized 1:1 to the artery is advanced onto a first (extraplaque) guidewire and inflated across the distal cap. This will create transient fenestrations between the extraplaque space and the true lumen, and targeted reentry into the true lumen can be achieved by engaging these fenestrations with a second polymer-jacketed guidewire (Figure 11.16) [50]. After its initial formulation, AFR showed moderate success rates of 65.9% in a multicenter registry [51]. However, extensive data about the reproducibility of AFR and long-term outcomes is warranted. The expansion of the extraplaque space can make posterior reentry attempts difficult; in case, the first attempt becomes unsuccessful.

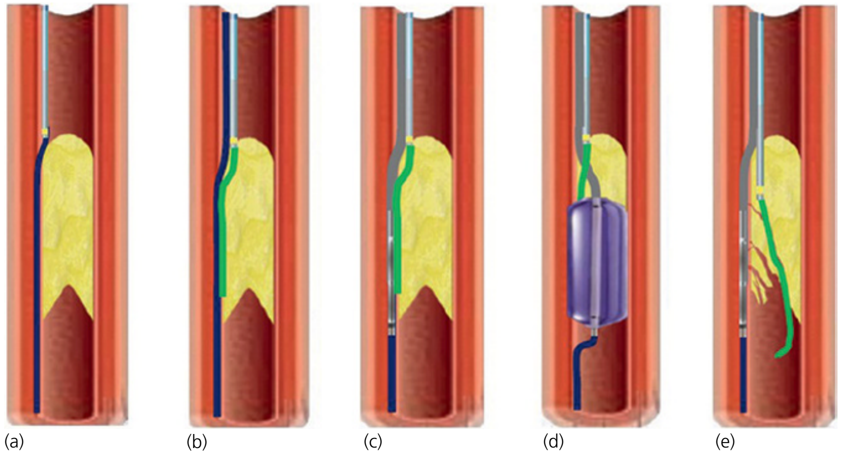


Figure 11.16 Schematic illustrations of antegrade fenestration and reentry. Source: Adapted from [50]. (a) Antegrade advancement of a guidewire into the extraplaque space in such a way that the distal tip gets positioned beyond the distal cap. (b) Removal of microcatheter from the first guidewire followed by introduction of second guidewire in the extraplaque space. (c) Advancement of balloon sized 1:1 with the vessel diameter over the first guidewire. (d) Inflation of the balloon in the extraplaque space. (e) Navigation of the second wire into the true lumen through the fenestrations (created between the extraplaque space and the true lumen) immediately following balloon.

A more recent modification of AFR, called subintimal AFR, involves the creation of larger and longer-lasting fenestrations between the false and true lumens through multiple inflations of the balloon along the entire occlusion, not just at the distal cap [52].

Tips and Tricks

****Stiff wire scratching to fenestration, de-escalation, and reentry technique** A novel wire-based procedure from extraplaque to intraplaque reentry technique is known as "stiff wire scratching to fenestration, de-escalation, and reentry technique". The microcatheter is progressed over the extraplaque workhorse wire to a point immediately preceding the anterograde or retrograde cap. Then, the wire is exchanged for a stiff wire like Gaia Second and Third/Confianza Pro12, Hornet 14. The operator needs to move the stiff wire back and forth, repeatedly, with changing wire rotation till it completes a 360° circle. The stiff wire can be navigated in variable lengths into the target, usually around 10–40 mm. Multiple microconnections between the extraplaque and intraplaque space are created by this foramination maneuver. In order to prevent further expansion of the dissection, wire knuckling should be prevented from the beginning. As the stiff wire is difficult to control and redirect, it is exchanged for a low tip load polymer-jacketed wire, like Fielder. This de-escalation improves the free movement of the wire and facilitates a smooth and uncomplicated reentry into the target true lumen (Figure 11.17) [53]. It is imperative that the microcatheter does not move from its initial position and knuckles in the guidewires are avoided to prevent the formation of hematoma that could compromise the success of the procedure. In case of failure, it does not preclude the alternative techniques.

Device-based ADR

Device-based ADR provides a more reliable and targeted method of reentry for CTO recanalization compared to wire-based reentry or uncontrolled knuckle-based reentry. Currently, there are two systems available on the market for device-based reentry: Stingray LP (Boston Scientific, USA) and ReCross (IMDS, Netherlands) microcatheter.

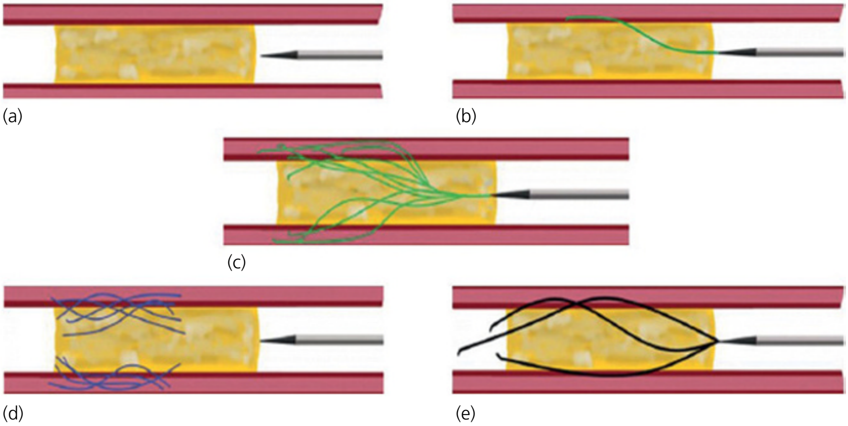


Figure 11.17 Schematic illustrations of stiff wire scratching to fenestration, de-escalation, and reentry technique. Source: From [53] / with permission of Via Medica. (a) Parking of microcatheter at proximal cap of CTO. (b) Penetration with extraplaque position of wire. (c) Scratching maneuver with a stiff wire back and forth with changing wire rotation (d) Creation of multiple micro connections between the extraplaque and intraplaque space. (e). De-escalation to low or intermediate tip load polymer-jacketed wire facilitating target true lumen entry.

Step-by-Step ADR with Stingray LP

1. Create an antegrade dissection plane.
2. Traverse a knuckled polymer-jacketed wire through the dissection plane to the desired position of reentry. The CrossBoss catheter can also be used in lieu of a knuckled polymer-jacketed wire to navigate the dissection plane, although its use has been decreasing due to its tendency to track into small side SB and after the introduction of dedicated knuckling wires (e.g. Gladius Mongo, Asahi Intecc Japan, Inc.).
3. Advance the Stingray LP system over the knuckled wire to the desired coronary position (usually near the tip of the knuckle) after appropriate preparation.
4. Inflate the Stingray LP system to 4 atm and remove the knuckled wire.
5. Adjust the angle of visualization until the Stingray system is visualized optimally as a straight line.
6. Perform retrograde angiography to guide the direction for reentry.
7. Use a stiff penetrative wire (e.g. Astato XS 20 or Gaia Next 3 [Asahi Intecc Japan, Inc.]) with a 45°, 1-mm bend to puncture the side port of the Stingray LP balloon toward the vessel lumen.
8. Once outward puncture occurs, rotate the wire so that the tip is parallel to the vessel and advance the wire in the direction of the distal vessel. If no resistance is met, perform retrograde angiography to confirm wire position.
9. If the wire is in the lumen of the distal vessel, trap out the Stingray LP system and exchange for a microcatheter, which will allow for further wire de-escalation [11, 54].

How to Troubleshoot Difficult Reentry?

If the wire fails to reenter the vessel, additional punctures can be performed with the stiff penetrative wire (stick-and-drive technique) through both ports as required. After a few punctures have been made, it is recommended to replace it with a polymer-jacketed wire (double-blind stick-and-swap method). The polymer-jacketed wire is then maneuvered out of the same Stingray ports, making repeated efforts to rotate and advance the wire toward the distal part of the vessel, akin to the Seldinger technique. Furthermore, the Stingray balloon can be deflated and either pushed forward or pulled back to a different location in the coronary artery ("bobsledding"), allowing the operator to reattempt puncturing after reinflating. This approach aids reentry by changing the orientation of the exit ports concerning vessel calcium or fibrosis [11, 54, 55].

Step-by-Step ADR with ReCross

The ReCross is specially designed as an oval-shaped microcatheter featuring two OTW lumens and a total of three exit ports. The white hub connects to two of these ports: the distal one and the more proximal of the two ports positioned 180° apart. The blue hub makes it possible to access the second exit port (between those accessible via the white hub). This microcatheter can be used for device-based ADR, as well as for parallel wiring or as a conventional microcatheter [56]. The steps of ADR are given as follows.

1. Prepare the ReCross catheter by flushing both lumens. The stylet must be removed from the blue port to allow for flushing and should be replaced prior to advancing the system over the wire into the body. The stylet allows for greater pushability when advancing the microcatheter.
2. Create an antegrade dissection plane.
3. Advance a knuckled polymer-jacketed wire through the dissection plane to the desired position of reentry.
4. Load the ReCross microcatheter via the port at the tip of the microcatheter and advance to the desired reentry position.
5. Once in position, remove the blue stylet.
6. A stiff penetrative wire is used to puncture toward the vessel lumen, similar to steps 7 and 8 of ADR with Stingray. Retrograde angiography can be performed to orient the direction of the puncture.
7. The ReCross microcatheter can be gently rotated to adjust the position of the exit ports relative to the vessel lumen with repeated attempts made at reentry through both hubs as needed. The microcatheter can also be retracted to adjust the position of the exit ports in relation to vessel calcium or fibrosis.
8. Once vessel reentry is achieved, the system is exchanged for a microcatheter, which can be used to deescalate the wire.

The "bougie technique" is an innovative strategy where a Stingray balloon can be used without using the CrossBoss to create an extraplaque space [57]. If a guidewire has entered the extraplaque space and crossed to the distal LZ, a microcatheter can be used to predilate the extraplaque space. A Stingray balloon is advanced to subsequently perform a reentry into the true lumen. It is difficult to deliver the Stingray balloon if the guidewire spirals around the vessel. Distal lumen compression can hinder reentry into the true lumen. This can be minimized by limiting the extraplaque space, preventing blood flow by inflating a balloon proximal to the CTO, or by advancement of a guide extension. The use of the Miracle 12 (Asahi Intecc, Japan) guidewire is highly recommended since it is a rigid wire without a hydrophilic coating and has high support in the most distal area, allowing exchanges to be performed more safely.

Tips and Tricks

****How to keep the hematoma small** The success of reentry can be reduced by large hematomas because they can be challenging to navigate. Hematomas can be minimized by plugging inflow with guide extensions when performing antegrade dissection A polymer-jacketed wire that forms a tiny knuckle, like the Gladius Mongo, can also aid in preventing large hematomas when utilizing a knuckled wire for dissection. Finally, prior to reentry attempts, the Stingray LP or ReCross microcatheter wire ports can be placed to negative suction using a 20-mL syringe to carry out the STRAW (subintimal transcatheter withdrawal) approach. This permits the hematoma to be aspirated [11].

Tips and Tricks

****Delivering the device** Proximal vessel calcification and tortuosity may hinder the delivery of both the Stingray LP system and the ReCross microcatheter. Guide extension catheter can be useful in overcoming tortuosity, as well as plugging inflow and reducing hematoma. It may be necessary to predilate proximal vessel calcification with small balloons (1.5–2 mm) to facilitate device delivery; however, using large balloons close to the intended site of reentry will result in a large hematoma and should be avoided.

WARNING

Limitations of the ADR Technique

Entering the extraplaque space proximal to the proximal cap can be difficult, especially in a non-diseased proximal vessel, a large-caliber vessel, and/or calcific arteries. The current device-based ADR is not advisable in situations where the distal lumen cannot be visualized by contrast medium, the distal cap of CTO is located at a bifurcation lesion, the plaque at the puncture site is thick, and the true lumen is collapsed or small [11].

Troubleshooting of Current ADR Techniques

Tip detection (TD) ADR is a new method originating from Japan that allows controlled and accurate reentry under live IVUS overcomes the limitation of current device-based ADR [58]. It enables reliable reentry in CTO-PCI by puncturing the wall between the extraplaque and the true lumen at the intended site with Conquest Pro 12 Sharpened Tip wire (CP12ST [(Asahi Intec, Japan]) under AnteOwl WR IVUS (Terumo, Japan) guidance. TD-ADR by CP12ST significantly reduces the length of the extraplaque space, total procedural time, and increases the success rate of ADR compared with Stingray-ADR (Figure 11.18a) by CP20 wire. The CP12ST wire has high penetration force, the TD method allows puncture regardless of the target size, and the Seldinger method under IVUS observation makes it possible to accurately insert the tip of the microcatheter into the true lumen (Figure 11.18b) [58].

SHARP THINKING

Default Tactics if the First Attempt Fails

If the wiring attempt of the initial strategy of ADR fails, there are many other techniques such as the "scratch-and-go" method, "move-the-cap," or limited dissection with subsequent wire subintimal entry (BASE technique). These techniques are discussed in detail in the following paragraphs.

GAME PLAN

Move the Cap

In this technique for "impenetrable" CTOs or CTOs with an ambiguous proximal cap, the extraplaque space proximal to the ambiguous or impenetrable cap is accessed with a stiff coronary wire followed by a microcatheter. This can be achieved in two ways: (1) directly with a method named "scratch and go" and (2) using slightly oversized balloon angioplasty to cause limited dissection to facilitate successful extraplaque wire entry. This method is called "balloon-assisted subintimal entry" (BASE). [59]

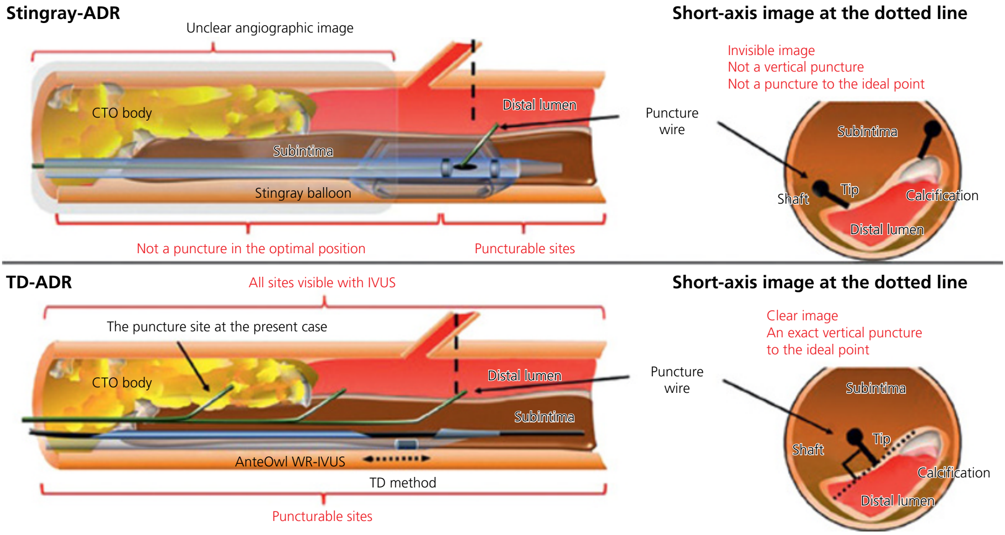

Stingray-ADR
Unclear angiographic image
CTO body
Distal lumen
Subintima
Stingray balloon
Not a puncture in the optimal position
Puncturable sites
Short-axis image at the dotted line
Invisible image
Not a vertical puncture
Not a puncture to the ideal point
Puncture wire
Subintima
Shaft
Tip
Calcification
Distal lumen
TD-ADR
All sites visible with IVUS
The puncture site at the present case
CTO body
Distal lumen
Subintima
AnteOwl WR-IVUS
TD method
Puncturable sites
Short-axis image at the dotted line
Clear image
An exact vertical puncture
to the ideal point
Puncture wire
Subintima
Shaft
Tip
Calcification
Distal lumen

Figure 11.18 Illustrations of the difference between Stingray ADR and TD ADR. Source: From [58] / American College of Cardiology Foundation / CC BY 4.0. Abbreviations: ADR, antegrade dissection reentry; CTO, chronic total occlusion; IVUS, intravascular ultrasound; TD, tip detection.

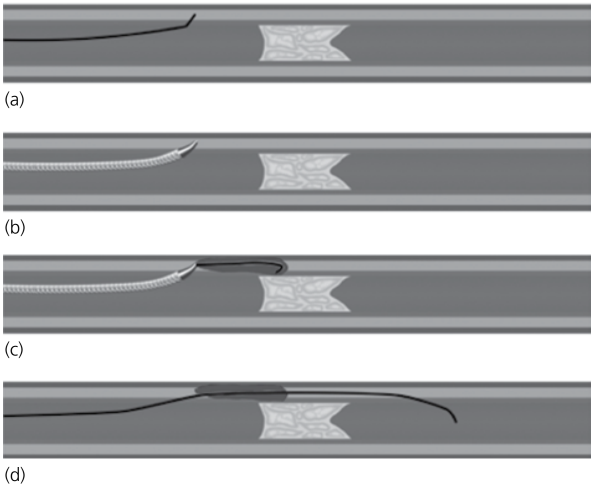


Figure 11.19 "Scratch-and-go" method to achieve the "move-the-cap" technique. (a) A high-tip-load wire such as a Confianza Pro 12 is used to puncture into the subintimal space proximal to the occluded segment. (b) A microcatheter is then advanced on this wire into the subintimal space. (c) A knuckle wire is advanced further distally in the subintimal space. (d) The dissection and reentry technique to gain distal true lumen wire position for subsequent stenting.

Tips and Tricks

*****The "scratch-and-go" technique** In the "scratch-and-go" technique, a high penetration tip wire with a long steep bend is used to puncture 1–2 mm into the subintimal space. A microcatheter is then advanced over this wire into the extraplaque space. This maneuver requires precise control of both wire and microcatheter to prevent prolapsing out of the extraplaque space. Once the microcatheter is secured in the extraplaque space, the stiff wire is exchanged for a soft polymer-jacketed wire that is then carefully advanced further into the extraplaque space, usually with knuckle technique (Figure 11.19).

*****Balloon-assisted subintimal entry (BASE)** With BASE, balloon-induced intimal disruption is performed proximal to the proximal cap using a balloon sized 1:1 to the artery at high pressure (Figure 11.20). In case of significant fibrosis and/or calcification, specialty balloons can also be used, such as cutting/scoring balloons or even an intravascular lithotripsy balloon [60]. In the case of a particularly resistant proximal cap, the balloon used for BASE can be reinflated as soon as the microcatheter is advanced into the extraplaque space so as to anchor the microcatheter and thus give more penetrative power to the knuckle (BASE power knuckle) [61]. When an SB is present at the proximal cap, a modification of this technique (side-BASE) can be used. A blocking balloon is positioned in the SB causing deflection of the knuckle wire into a dissection plane [62].

Notably, BASE should be preferred to the scratch-and-go technique, whenever feasible, because the latter is technically more challenging and potentially dangerous, as the penetrative wire can inadvertently perforate the vessel [63].

****Piercing the distal cap** When the wire reaches the exit point of the CTO, the wire should be manipulated gently and carefully to permit successful wire crossing. It is very important to control the wire tip, which is intentionally directed toward the distal true lumen. In most cases,

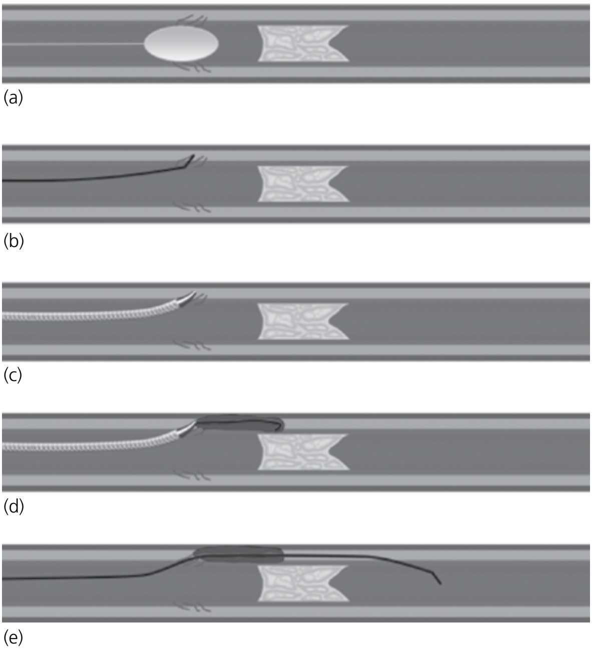


Figure 11.20 “Balloon-assisted subintimal entry” method to achieve the “move-the-cap” technique. (a) Inflation of a slightly oversized balloon in the proximal vessel creates controlled dissection. (b) The dissection facilitates wire entry into the subintimal space proximal to the occluded segment. (c) A microcatheter is then advanced on this wire into the subintimal space. (d) The knuckle technique is used to extend dissection further distally. (e) The dissection reentry technique is used to secure the distal true lumen for stenting.

once the wire tip is advanced into the distal true lumen, the resistance at the wire tip suddenly yields, but it is still very important to confirm that the wire tip is within the lumen of the coronary artery. This confirmation can be made by acquiring angiographic views to confirm that the wire tip can be advanced up to the distal end of the artery without any resistance [21].

Although most studies have not demonstrated a role for debulking of CTOs to reduce restenosis, excimer laser or high-speed RA, or use of the Tornus catheter, may allow balloon passage or expansion of otherwise non-dilatable CTOs. The tactical decisions of crossing a CTO lesion with its preferred sequence of different techniques – from simple to complex, from user-friendly to labor-intensive, and from low-cost to expensive – are listed in Box 11.2.

BOX 11.2 BEST OPTIONS FOR BALLOON TO CROSS A CTO

1. **No added Cost FIRST Best Maneuver:** Deep-seat the guide
2. **$⌛ SECOND Best Maneuver:** Advance a second wire along the first wire to straighten the artery or to widen the lumen for balloon passage
3. **$⌛ THIRD Best Maneuver:** Advance a second wire to a side branch to anchor the guide
4. **$⌛⌛ FOURTH Best Maneuver:** Inflate an OTW balloon in the proximal segment to anchor and deep-seat the guide
5. **$$⌛ FIFTH Best Maneuver:** Change to a stronger guide
6. **$$⌛⌛** 💧💧 Debulking atherectomy

RETROGRADE APPROACH

Introduction

The retrograde approach involves navigation of a guidewire through a CC into the distal true lumen, followed by CTO crossing using various techniques. CTO crossing is often easier in the retrograde direction because the distal CTO cap is often less fibrocalcific, and more tapered, because it has been exposed to lower pressure compared with the proximal cap [5]. The success rate of CTO PCI has gone up significantly from 70% to 95% in recent years with the advent of the retrograde approach [63–66].

Step 1: When to go retrograde?

The antegrade route by default remains the primary approach because it may be successful and whether or not it fails, antegrade preparation is required for completing the retrograde crossing. It is critical to assess the eligibility of the patient and therefore the lesion for a retrograde approach so as to be prepared to alter the strategy. Retrograde crossing techniques are most commonly favored when an antegrade approach is unsuccessful. However, for selected lesions, an upfront (primary) retrograde approach is also favored, like flush aorto-ostial CTOs, tortuous CTO course, CTOs with proximal cap ambiguity, bifurcation at the distal cap, severe proximal tortuosity or calcification, diffuse disease or poorly visible distal vessel, and CTO vessels that are difficult to engage, like anomalous coronary arteries [67]. Dedicated tools along with an operator expertise, in addition to appropriate CCs, are critical to the success of retrograde CTO PCI.

Step 2: Selecting the CC

Meticulous analysis of all potential CCs is of paramount importance. Bypass grafts, septal, or epicardial CCs could be utilized to embark on retrograde approach. Assessment of CC size (which is sometimes evaluated using the Werner classification), tortuosity; angles of entry and exit; bifurcations; and distance from the CC exit to the distal cap are critical to the success of retrograde technique [68]. Septal CCs are the safest and should be the default choice whenever feasible (Figure 11.21). Severe septal tortuosity instead of size impedes the wire navigation. Compared with the epicardial, the septal CCs usually are multiple with a large range of selection. They usually are straighter than the epicardial vessels. Injury or perforation of septal CCs is less likely to cause acute MI, myocardial hematoma, or pericardial tamponade compared to epicardial CC perforation. Additionally, they may be dilated employing a small balloon (1.20–1.5 mm) with very low pressure inflation (2–4 atm) for smooth navigation of microcatheter [12].

Larger, less tortuous CCs are simpler to cross and should be considered as a first choice. Many times, faintly visible or invisible (Werner class 0) septal CCs can frequently be crossed, especially when “surfing” with the wire. CCs should be chosen after adequate vasodilation and utilizing the right angiographic projection (often anteroposterior or right anterior oblique with cranial angulation for septal CCs that lengthens the CCs at the entry and exit site) [65]. It is important to ascertain that both the donor and recipient vascular angles are less than 90°. The entry of the CC into the recipient vessel should not be too close to the distal cap.

Epicardial CCs (25–38%) and bypass grafts (5–13%) are the next most often used after septal CCs (50–65%) [70–72]. Venous grafts are large, less tortuous, and devoid of SBs and hence provide excellent conduits [73]. Epicardial CCs are favored less due to more tortuosity and higher risk of perforation and tamponade. Internal mammary artery grafts should be used with caution due to risk of vessel injury and hemodynamic compromise [74].

Step 3: Getting to the CC

The donor vessel (i.e. the non-CTO vessel, which provides the CC through which the retrograde equipment is advanced) should be initially wired using a workhorse guidewire for protection if a complication (such as dissection) occurs. The retrograde guide catheter should

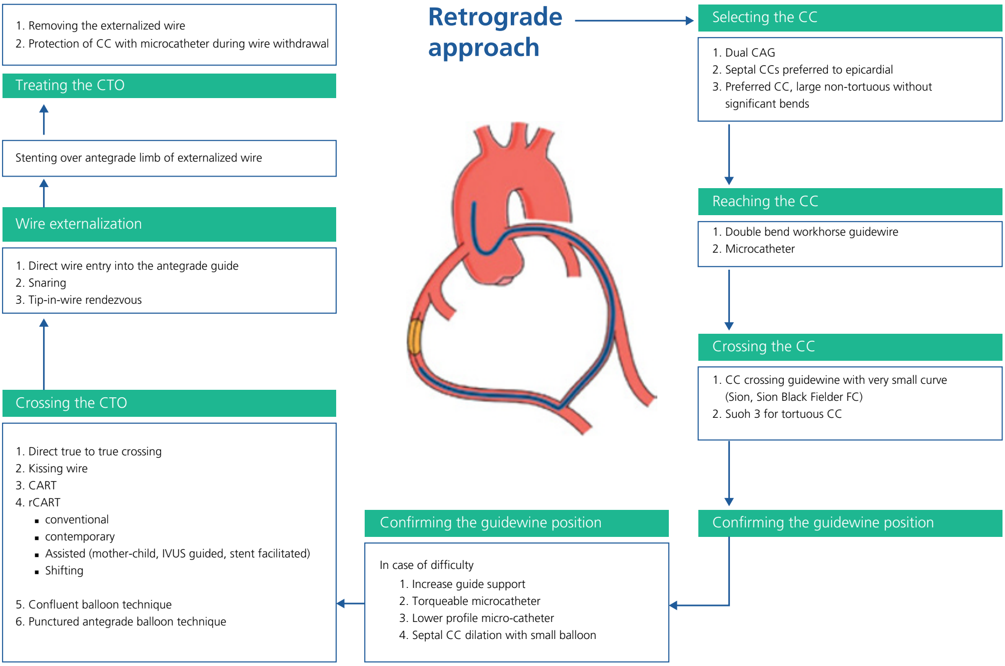

Retrograde approach
Selecting the CC
1. Dual CAG
2. Septal CCs preferred to epicardial
3. Preferred CC, large non-tortuous without significant bends
Reaching the CC
1. Double bend workhorse guidewire
2. Microcatheter
Crossing the CC
1. CC crossing guidewine with very small curve (Sion, Sion Black Fielder FC)
2. Suoh 3 for tortuous CC
Confirming the guidewine position
Confirming the guidewine position
In case of difficulty
1. Increase guide support
2. Torqueable microcatheter
3. Lower profile micro-catheter
4. Septal CC dilation with small balloon
Crossing the CTO
1. Direct true to true crossing
2. Kissing wire
3. CART
4. rCART
conventional
contemporary
Assisted (mother-child, IVUS guided, stent facilitated)
Shifting
5. Confluent balloon technique
6. Punctured antegrade balloon technique
Wire externalization
1. Direct wire entry into the antegrade guide
2. Snaring
3. Tip-in-wire rendezvous
Stenting over antegrade limb of externalized wire
Treating the CTO
1. Removing the externalized wire
2. Protection of CC with microcatheter during wire withdrawal

Figure 11.21 Schematic illustration of steps of retrograde approach. Abbreviations: CAG, coronary angiography; CC, collateral channel; CTO, chronic total occlusion; CART, controlled antegrade and retrograde subintimal tracking; rCART, reverse controlled antegrade and retrograde subintimal tracking; IVUS, intravascular ultrasound.

ideally be short (e.g. 90 cm), especially when the distance between the ostium of the donor vessel and the ostium of the CTO vessel through the CC is long. A workhorse guidewire is typically advanced through a long (150 or 155 cm) microcatheter to reach the CC, minimizing any injury to the donor vessel. To enter septal CCs, a double bend on the wire or an angled-tip microcatheter may be needed. Once the guidewire enters the CC, it is followed by a microcatheter. The choice of larger or smaller diameter microcatheters should be based on the size and morphology of the CC. If a stenosed vessel is crossed with the microcatheter, it is safer to test for preserved flow in the distal donor artery before attempting to cross the CC [75].

Step 4: CC navigation

The CC crossing technique depends on the CC being used. For septal CCs, either a surfing or a contrast-guided technique can be used, whereas contrast-guided crossing should be used for epicardial CCs and bypass grafts. Surfing is a very efficient crossing method in which a guidewire is advanced rapidly with simultaneous rotation until it either buckles or advances into the distal target vessel. If the wire buckles, it is withdrawn and redirected, searching for a path of least resistance. Occasionally, premature ventricular contractions (PVCs) can occur. A frequent or repetitive PVC indicates suboptimal wire tip position, myocardial irritability, and herald CC injury. It is critical to avoid forceful navigation of the guidewire to avert perforation that makes the septal CC unusable [12].

Contrast-guided technique involves injection of 100% contrast after aspiration of blood utilizing a 3-mL luer-lock syringe under cineangiography with appropriate angiographic projections (e.g. right anterior oblique with cranial or caudal angulation for septal CCs). To minimize subsequent stickiness, the microcatheter is flushed before reinserting guidewire. The guidewire is advanced toward the CC once clear connection is established. Epicardial CC crossing should always be performed using contrast guidance and without surfing because of high risk for perforation. Crossing during diastole may be easier. Deviations from the observed path can lead to perforations. The most commonly used guidewires for crossing CC are Fielder XT-R, Sion, Sion Black, and Suoh 03 (Asahi Intecc, Aichi, Japan), the latter being preferred in epicardial CCs and increasingly septal CCs as well (Figure 11.21).

Step 5: Confirming the wire position

After apparent guidewire crossing, retrograde vessel angiography should be performed before advancing the microcatheter to confirm that the guidewire has entered into the distal true lumen. Occasionally a CC may appear to be a septal in one projection but may in reality be epicardial; such CCS have higher risk of rupture; a classic example is used in acute marginal CC supplying the RCA from the distal LAD artery. Obtaining an orthogonal view can help clarify the CC type and location.

Step 6: Crossing the CC with the microcatheter

The microcatheter navigation can be performed either by push or by rotation depending on its construction. If the microcatheter fails to advance through the CC, various techniques can be employed, such as increasing support (deep-seating, SB anchor, or a guide catheter extension) or using a different torqueable lower profile microcatheter or shorter microcatheter (Figure 11.21). Additionally, a small balloon (1.0–1.5 mm) may be inflated at a low pressure (2–4 atm) in Septal CCs. Alternatively, direct retrograde wire crossing can be attempted without advancing the retrograde microcatheter (especially for short occlusions), or the retrograde wire may serve as a marker to facilitate antegrade crossing (kissing wire). Failure of all attempts may lead to selection of a different CC.

Step 7: Crossing the CTO

There are various methods to cross the CTO, once the CC has been navigated successfully and retrograde microcatheter advanced to the distal cap.

1. **Retrograde true-to-true crossing**
   The fastest way is when a retrograde wire is directly passed into the proximal true lumen known as intraplaque crossing (Figure 11.21, 11.22a). This is suitable for short occlusions (<20 mm), especially when the distal cap is tapered, but it is successful in less than 30% of cases. The microcatheter is advanced near the distal cap. A directed penetration or directed navigation wire is advanced to breach the distal cap and advance through the occlusion. The probability of retrograde wire crossing can be enhanced by coaxial anchor (inflating a retrograde balloon) and using a stiffer, tapered-tip, and/or hydrophilic wires. IVUS plays a crucial role to guide retrograde guidewire into proximal true lumen [12, 76].
2. **Kissing wire technique**
   The retrograde guidewire may be utilized as a guide or marker for manipulation of the antegrade guidewire (Figure 11.21, Figure 11.22b). If the two guidewires fail to overlap precisely, one of them may have entered an extraplaque space. Antegrade wiring should be initiated from a site proximal to the retrograde wire so that the tips of the two guidewires can meet at a single point [12, 76].
3. **RDR**
   RDR involves CART)or rCART technique, or a variation thereof. Subsequently, there are four possible fates (for both antegrade and retrograde wire requiring different strategies (Table 11.3) [77]. The scenario becomes most favorable with subintimal position of both antegrade and retrograde wires. An antegrade balloon is inflated that successfully connects both sides. This is most widely performed RDR technique called as rCART. The scenario becomes least favorable when the antegrade wire is intimal and the retrograde one is subintimal. This situation warrants creation of a space by aggressive antegrade dilatation of CTO body for successful navigation of retrograde wire. When both the antegrade and retrograde wire are intimal, either wire is advanced antegradely or retrogradely with the opposing wire as a landmark toward the opposite channel called as "kissing wire technique." Antegrade balloon dilatation is the next strategy for retrograde navigation of wire. If this fails, the author purposefully embarks on antegrade or retrograde subintimal tracking. A CART procedure has been employed when the antegrade wire is subintimal and retrograde wire intimal (Table 11.3).
4. **CART**
   The standard CART (Figure 11.22c) is executed by navigating both the antegrade and retrograde wire into parallel subintimal spaces in the CTO. A small monorail NC balloon (2.0–3.0 mm diameter) is then advanced over the retrograde wire into the distal CTO subintimal space. The antegrade wire is directed toward the retrograde balloon which is

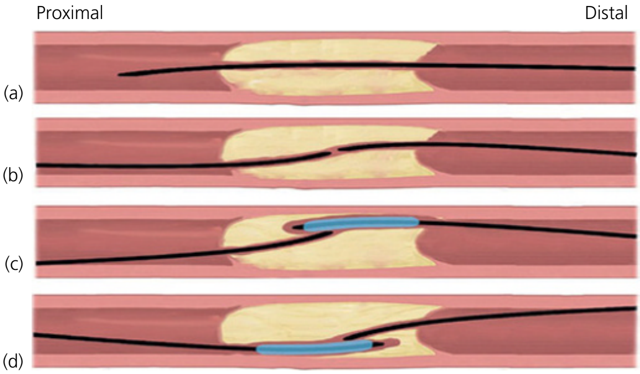


Figure 11.22 Schematic illustration of retrograde techniques. (a) Retrograde true to true crossing. (b) Kissing wire technique. (c) Controlled antegrade and retrograde tracking (CART). (d) Reverse CART.

Table 11.3 **Successful retrograde guidewire crossing by connecting antegrade and retrograde channels**

Guidewire position	Preferred strategy
Intimal antegrade and retrograde guidewire	1. Kissing wire technique 2. Antegrade balloon dilatation 3. Antegrade or retrograde subintimal tracking
Subintimal (most favorable) antegrade and retrograde guidewire	1. rCART
Intimal antegrade and subintimal retrograde guidewire	1. Aggressive antegrade balloon dilatation for CTO body disruption and opening of a passage
Subintimal antegrade and intimal retrograde intimal guidewire	1. rCART 2. CART as second line with caution

rCART, reverse controlled antegrade and retrograde subintimal tracking technique; CART, controlled antegrade and retrograde subintimal tracking technique.
Source: Adapted from [77].

then inflated to enlarge the subintimal space. With deflation of the retrograde balloon, the antegrade wire sweeps into the distal true lumen. It is followed by antegrade stenting of CTO [78]. Minimization of length of the subintimal tracking is the advantage of this technique. It is not always feasible to advance a retrograde balloon inside the occlusion, particularly in complex lesions. The subintimal space may extend toward the proximal true lumen of the CTO and may cause a fatal (e.g. dissection of the left main) event with occlusion of the proximal segment of the left coronary system [80]. The standard CART is rarely done nowadays and is replaced with rCART. However, this technique still may be employed in some cases of ostial CTOs, heavily calcified CTOs, and when the retrograde equipment is not long enough to reach antegrade guiding catheter (with long epicardial CCs and enlarged heart) [76, 79].

5. **rCART**
   rCART is the most widely employed RDR technique. It is technically more straightforward to embark on than CART as this method avoids the need to track a large balloon through the CCs. A balloon is inflated over the antegrade wire, followed by retrograde guidewire navigation into the space created by the balloon. (Figure 11.22d). In case of failure, larger antegrade balloons are used to create larger dissection. Multiple iterations of rCART are used in CTO PCI [80].
6. **Conventional rCART**
   The conventional rCART (Figure 11.23) starts with a longitudinal overlap of the antegrade and retrograde guidewires. The conventional wiring in both an antegrade and a retrograde fashion is easier to make an overlap with unambiguous course of the CTO segment. This is not only inconvenient but also carries the risk of vessel perforation with CTO vessel course ambiguity, severe tortuosity, or heavy calcification. Knuckle wire technique can be a key to solution in this scenario. A low (Fielder XTA) to intermediate penetration force polymer-jacketed guidewires (Gaia Second/Third), Pilot 200 with a knuckle (an umbrella-type bend or loop), is advanced via the microcatheter through CTO body within the subintimal space to establish retrograde BO. An antegrade BO is established by positioning a microcatheter at proximal cap and using a low to intermediate penetration force guidewire to breach the proximal cap to enter subintimal space. Then an appropriately sized antegrade balloon is advanced to the point of guidewire overlap and inflated which creates or enlarges intimal/subintimal dissection and makes a connection between the spaces, known as common

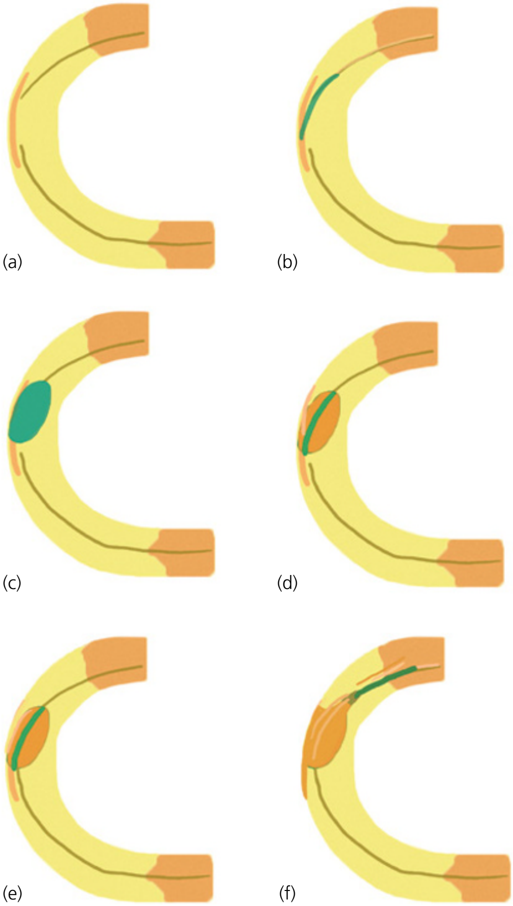


Figure 11.23 Schematic illustration of the conventional reverse CART technique. Source: Reproduced with permission from [80] / The Korean Society of Cardiology / CC BY-NC 4.0. (a). A longitudinal overlap of the antegrade and retrograde guidewires in a case of proximal RCA CTO. (b). Delivery of a balloon over the antegrade guidewire to the point of guidewire overlap. (c). Inflation of the balloon. (d). Creation of a connection is between the spaces (common subintimal space [CSS]) containing both the guidewires. (e). Navigation of the retrograde guidewire through the CSS. (f). The subsequent advancement of the retrograde guidewire into the proximal true lumen.

subintimal space (CSS) [66, 80, 81]. Sometimes, a larger antegrade balloon may be required to maximize the possibility of CSS formation. Usually, a low to intermediate penetration force wire is used as the retrograde guidewire to track the created CSS. In the event of subintimal position of antegrade wire and intimal position of the retrograde wire, a high penetration force guidewire (Gaia Third, Conquest 12, Hornet 14) may be required [82].

7. **Assisted rCART**

In case of failure of the retrograde wire navigation in the antegrade guide even after few tissue ablations, a guide-extension catheter (Guideliner [Vascular Solutions, Minneapolis, MN, USA], Guidezilla [Boston Scientific, USA]) can be deployed in the subintimal space to facilitate the process (mother–child rCART). Alternative strategies include IVUS guidance, the use of larger balloon to achieve greater tissue ablation, the use of smaller balloons with retrograde navigation of Gaia series of wires (contemporary rCART), the use of cutting or scoring balloon, and the deployment of stent in antegrade subintimal space for successful retrograde navigation of wire (stent-assisted rCART) or movement of BO operation overlap zone to a different location (shifting rCART) [69, 71].

8. **IVUS-assisted rCART**
   IVUS provides information on the optimal balloon size for medial disruption, exact position of the connection between the intima and subintima and visual information on the distance of the retrograde wire to the intima. In the event of CSS recoil, redilatation with a larger balloon may be employed [12].
9. **Stent-facilitated rCART**
   This technique involves implantation of a stent from the antegrade true lumen into the subintimal space created by antegrade balloon inflation which enables rapid navigation of retrograde wire into the proximal true lumen by forming a clear open target (Figure 1). However, this is limited by its inability to remove the stent once deployed. This may result in stent thrombosis due to proximal thrombus propagation if there is a failure to connect between the antegrade and retrograde true lumen [66, 80].
10. **Cutting or scoring balloon-facilitated rCART**
    In this technique, an antegrade cutting balloon such as Wolverine (Boston Scientific, MA, USA) or scoring balloon such as Angiosculpt (AngioScore, CA, USA) is used to perform angioplasty, enhancing the trauma to the intima to maximize fenestration between the subintimal space and true lumen and decompress any subintimal hematoma.
11. **Mother–child reverse CART**
    The mother–child concept, an elegant modification of reverse CART (rCART), involves the use of a guide-extension catheter such as Guideliner (Vascular Solutions, Minneapolis, MN, USA) and Guidezilla (Boston Scientific, USA) into antegradely created subintimal space to facilitate retrograde wire navigation into proximal true lumen (Figure 11.21). Unlike the stent, the guide extension device may be removed or repositioned in the event of failure to connect between the antegrade and retrograde true lumen [66, 82].
12. **Contemporary rCART**
    The conventional rCART with a larger balloon may create an undesirable intentional intimal/subintimal dilatation leading to distal propagation of the hematoma and vessel perforation. The conventional rCART is also limited by subsequent coronary artery aneurysm and increased risk for target vessel revascularization due to longer stent length [83, 84]. Moreover, excessive manipulation of the retrograde wire or use of a knuckle wire technique can enlarge a space around the retrograde wire that may prevent the precise directional control of the same wire. The contemporary rCART technique aims to minimize vessel trauma and to make the procedure more efficient through a precise directional control by efficient use of deflection mechanisms of the retrograde guidewire (Gaia series [Asahi Intecc, Japan]). The key steps of this technique include: (1) antegrade preparation; (2) use of a small antegrade balloon as a target for the retrograde wire; and (3) retrograde intentional vessel tracking using a guidewire with high torque control (Figure 11.24, 11.25) [66, 81].

    An antegrade guidewire is navigated through the occlusion with the support of a microcatheter to within 5 to 10 mm of the distal cap of CTO. The antegrade guidewire should not be advanced beyond the CTO segment to minimize the risk of hematoma. Next, a small balloon (2.0 mm diameter in most cases) is advanced toward the tip of the guidewire. Except for a proximal cap ambiguity or uncertainty of CC crossing, antegrade preparation is performed first as it minimizes donor artery risk and ischemic time of the CTO territory, and encourages going directly to rCART after retrograde CC crossing.

    The retrograde CTO segment wiring is commenced using a guidewire with good torque control and high penetration efficiency (Gaia series). This retrograde wire should be

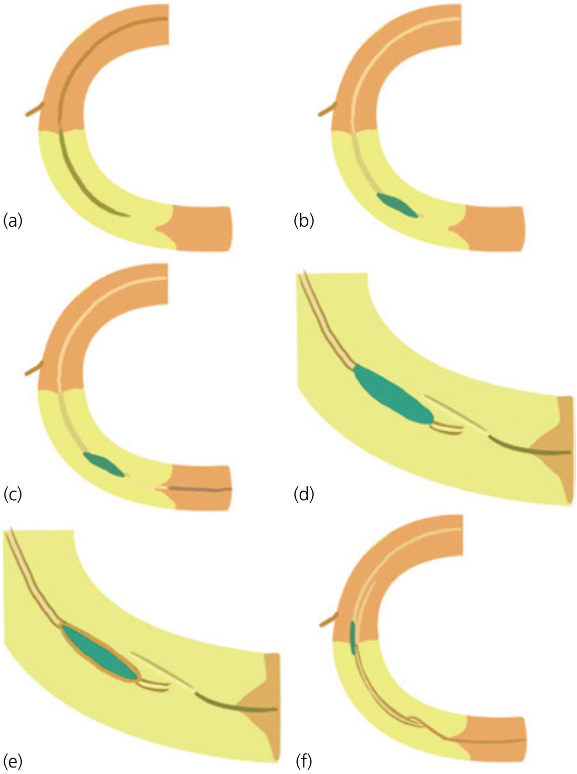


Figure 11.24 Schematic illustration of contemporary reverse CART. Source: Reproduced with permission from [80] / The Korean Society of Cardiology / CC BY-NC 4.0. (a) Antegrade preparation depicting navigation of an antegrade guidewire through the occlusion until 5–10 mm proximal to the distal cap with the support of a microcatheter in a case of mid RCA CTO. (b) Advancement of a small balloon to the tip of the antegrade guidewire. (c) Navigation of the retrograde guidewire toward the antegrade balloon after the collateral channel crossing by a guidewire and a microcatheter. (d) The manipulation and gentle push of the retrograde guidewire toward the inflated antegrade balloon catheter (retrograde wire is lateral to balloon in this figure). (e) Navigation of the retrograde guidewire into the space (created by the balloon) after balloon deflation. (f) Negotiation of the retrograde guidewire into the proximal true lumen with sequential antegrade balloon inflation within the CTO segment proximal to the connecting point.

navigated without excessive torquing and directed toward the antegrade balloon so that the shaft of the antegrade balloon and the retrograde wire are as coaxial as possible at the point of puncture. The retrograde puncture should aim toward the end of the balloon first (end balloon wiring technique) and, if this fails, toward the lateral side of the balloon (lateral balloon technique). After gently pushing the retrograde wire, the antegrade balloon is deflated, allowing the same retrograde wire to sneak into the space created by the antegrade balloon. However, it is not advisable to embark on the contemporary rCART in CTO cases with ambiguous proximal cap, severe tortuosity, and heavy calcification because of the need for antegrade preparation before adopting a retrograde CTO segment wiring, and the knuckle wire technique cannot be contemplated to advance the antegrade or retrograde wire as it is likely to create large spaces around the guidewires resulting in reduced retrograde wire control. Also, the short segment (<15 mm) CTOs are not suitable

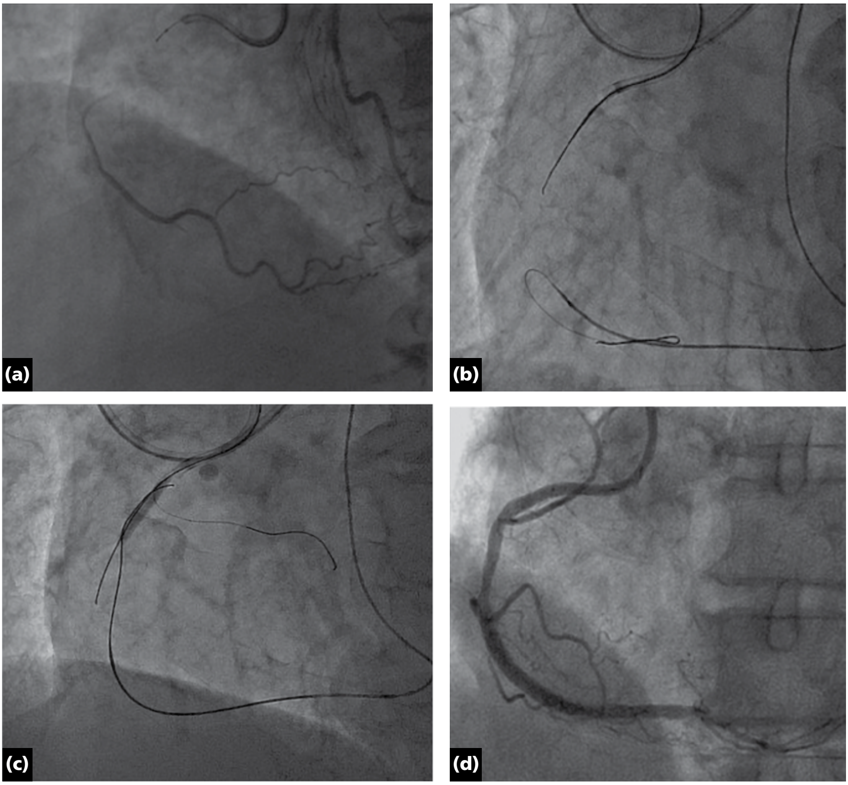


Figure 11.25 Depiction of contemporary reverse CART. (a) A baseline coronary angiogram depicting CTO of proximal RCA with good septal collateral from LAD. (b) Subintimal position of antegrade guidewire. (c) Antegrade small (2 mm) balloon inflation followed by retrograde penetration of wire into proximal true lumen. (d) Final result after wire externalization and three overlapping DES.

for the contemporary rCART, because of difficulty in embarking on antegrade preparation without extending the hematoma beyond the distal cap. The antegrade or RWE works well for short segment CTOs.

13. **Shifting rCART**
    Either proximal or distal propagation of the intimal/subintimal dissection beyond the CTO segment is designated as the shifting rCART (Figure 11.26). The antegrade balloon is parked and dilated outside the CTO segment (either proximal or distal) which is followed by navigation of retrograde wire through the connection created. This technique is suitable in cases where antegrade preparation or retrograde cap penetration is not feasible and where there are no significant SBs close to the site of the rCART technique [80, 81].
14. **Confluent balloon technique**
    Confluent balloon r rCART involves simultaneous inflation of both antegrade and retrograde balloon in a kissing fashion with the goal of creating communicating subintimal space which permits retrograde wire navigation into proximal true lumen [65, 85].
15. **Punctured antegrade balloon technique**
    In this technique, the antegrade balloon is kept inflated during retrograde crossing attempts and is punctured by the retrograde wire. Subsequently, the retrograde wire is advanced, while the punctured antegrade balloon is retracted [86].

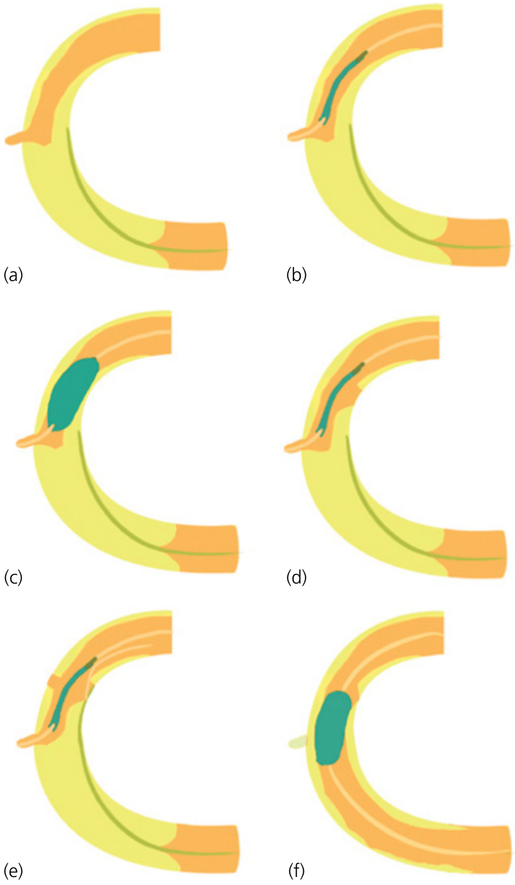


Figure 11.26 Schematic illustration of shifting reverses CART. Source: Reproduced with permission from [80] / The Korean Society of Cardiology / CC BY-NC 4.0. (a) Navigation of a retrograde guidewire into the subintimal space in a case of mid RCA CTO with a small side branch around the proximal cap. (b) Negotiation of an antegrade balloon to the planned connecting point. (c) Inflation of the antegrade balloon in an attempt to create a medial dissection. (d) Creation of a connection between the retrograde subintimal space and the proximal true lumen after balloon deflation. (e) Navigation of the retrograde guidewire into the proximal true lumen through the created connection. (f) Performance of the guidewire externalization and balloon dilatation.

Step 8: Guidewire externalization

The retrograde wire is advanced into the antegrade guide catheter, either directly or through an antegrade guide extension catheter (i.e. mother–child rCART). Once the retrograde wire is positioned in the antegrade guide, the microcatheter is advanced further into the antegrade guide or guide extension. The retrograde wire is removed and exchanged for a long, specially designed externalization wire (RG3 [Asahi Intecc, Japan; 330 cm long, 0.010 inch] or R350 [Vascular Solutions, USA; 350 cm long, 0.013 inch]). The Y connector of the antegrade guide is removed to facilitate atraumatic externalization of the wire and the Y connector is then replaced over the guidewire. After successful externalization, the distal tip of the microcatheter is pulled back to the distal true lumen of the target vessel. Subsequently, PCI is performed over the retrograde wire. It is critical to protect the CCs always by a microcatheter during advancement or withdrawal of the externalization wire, and a torque should be placed on the retrograde end of the wire to prevent excessive pull of the wire from the antegrade side [12, 13]. Another method to externalize the retrograde wire includes snaring the wire in the aorta typically with tulip snare through the antegrade guide.

Step 9: Retrograde guidewire connection and antegrade conversion without externalization

The development of advanced variants along with traditional techniques to establish retrograde guidewire connection and antegrade conversion has led to the establishment of techniques that serve as strategic advantages in retrograde CTO-PCI, providing a valuable and feasible alternative to conventional retrograde connection techniques, particularly when those techniques fail. Their ability to avoid the externalization process reduces potential damage to CCs and the ostium of the donor artery, potentially leading to a reduction in complication rates.

1. **Tip-in the microcatheter technique**

   The "tip-in" technique serves as an alternative externalization method when the retrograde guidewire successfully crosses into the antegrade guide catheter, but the retrograde microcatheter fails to cross or and advancement of the retrograde microcatheter is considered to carry high risk for CC injury.

   The conventional tip-in technique involves intubating an antegrade MC with the retrograde guidewire that has successfully crossed the CTO body and entered into the antegrade guide catheter. Subsequently, the antegrade MC is advanced over the retrograde guidewire through the CTO. The retrograde guidewire is removed, allowing for the advancement of an antegrade workhorse guidewire over which PCI is performed [87]. The connection can be performed anywhere in a guide extension or the guide catheter but is usually best accomplished by having the retrograde guidewire tip positioned at the most angulated outer curve of the antegrade guide catheter. The connection can be performed by either advancing the retrograde guidewire into the antegrade microcatheter or by advancing the antegrade microcatheter over the retrograde guidewire. The tip of the retrograde guidewire and the tip of the antegrade microcatheter tend to meet at the same point on the outer curvature, which facilitates guidewire insertion into the microcatheter tip. Balloon-assisted tip-in can facilitate the connection by inflating a small balloon next to the tip of the antegrade microcatheter, which can also reduce the movement of the microcatheter tip [88].

   The poor coaxial alignment often results in failure which can be corrected by adjusting the microcatheter tip's position or shaping the retrograde guidewire with a 60° bend, 2–3 mm from the tip, though this may require removing the guidewire.

   Additional troubleshooting options include (1) the manual microcatheter-tip modification [89] for precise steering toward the shaft of a preshaped microcatheter; (2) the "hula hoop" technique, using a bent guidewire back end to enhance microcatheter tip control; (3) positioning a small coronary balloon (2.0–2.5 mm) near the microcatheter's distal tip to align it more closely with the guide catheter's outer curvature; (4) removing unnecessary equipment from the guide catheter to better determine whether the retrograde guidewire is on the "left" or "right" side of the microcatheter; (5) increasing X-ray magnification and collimation to improve visibility; and (6) the ping-pong technique in case of using a separate guide catheter for the connection [90].

2. **Facilitated tip-in technique**

   This is an enhancement of the traditional tip-in technique, designed to increase the support of the antegrade microcatheter using the back end of a workhorse 0.014 inch guidewire when the antegrade microcatheter fails to cross on the retrograde guidewire [91]. It involves the use of the back end of a guidewire instead of preloading the antegrade MC with a workhorse guidewire. This adjustment increases antegrade microcatheter support, thereby facilitating the advancement of the antegrade microcatheter over the retrograde guidewire.

3. **Bite-in technique**
   The conventional tip-in technique can sometimes be challenging because of the low control of retrograde wire manipulation or retrograde wire deformation. Therefore, we developed a novel strategy termed "bite in" to overcome this issue. The conventional tip-in technique has been replaced by advancing the antegrade microcatheter through Guidezilla (Boston Scientific) with moderate rotation, allowing it to capture the retrograde wire like a fish biting a hook without the retrograde wire manipulation. Then, it allows the antegrade microcatheter to traverse the occluded segment along the retrograde wire to facilitate microcatheter passage [92].
4. **Tip-in the balloon technique**
   This technique uses a conventional antegrade coronary balloon instead of a microcatheter for performing the tip-in maneuver over the retrograde guidewire when guidewire externalization is not desired (when crossing epicardial collaterals) or when an externalization guidewire is not available or the CTO body cannot be crossed with the antegrade microcatheter after a successful tip-in the microcatheter [93]. A balloon is positioned similarly to the antegrade microcatheter as in the conventional tip-in technique. The retrograde guidewire is advanced toward the tip of the balloon, and if they come into contact, a slight deflection of the guidewire's tip can be observed. At this point, the guidewire is gently pullback and rotated clockwise or counterclockwise to intubate the tip of the balloon. The maneuver is similar to the tip-in the microcatheter without the option of rotating and directing the rapid-exchange balloon catheter. After successful lesion dilatation and if antegrade conversion is still not possible, stenting can be performed in the same fashion [93].
5. **Rendezvous technique**
   This technique involves inserting an antegrade guidewire from an antegrade microcatheter into the retrograde microcatheter, traditionally performed inside the antegrade guide catheter. It is indicated when the retrograde microcatheter fails to cross the CTO and the retrograde guidewire cannot be intubated into the antegrade guide catheter or guide extension or when the antegrade microcatheter is very close to the retrograde microcatheter tip [94]. The kissing guidewire technique is frequently the initial step, positioning both guidewires close together for easier manipulation.

   If challenges arise, highly supportive, soft-tip guidewires and techniques like the chasing guidewire method – simultaneously pushing and pulling the wires – can improve success. To further improve guidewire maneuverability, advancing the two microcatheters very close together within the CTO lesion – a scenario known as kissing microcatheters can be beneficial [88].
6. **Closed-loop trapping technique**
   In ipsilateral cases using a single guide catheter where the antegrade microcatheter struggles to penetrate the CTO, a trapping technique can enhance the antegrade system's force toward the CTO. Positioning the microcatheter or balloon near the proximal cap and gently pulling on the trapped retrograde guidewire draws the antegrade guide catheter and the contained microcatheter or balloon toward the CTO body [94].
7. **Catch-it technique**
   Catch-it involves intubation of the retrograde guidewire into the antegrade guide catheter in the aortic arch or the subclavian artery [95]. This maneuver is simple and avoids snaring. The retrograde guidewire is navigated into the ascending aorta, using the aorta's natural curve for alignment with the antegrade guide catheter, which can also be straightened by inserting the back end of a 0.035-inch guidewire. Similar to the tip-in technique, the goal is to directly intubate the guide catheter with the retrograde guidewire at the outer curvature of the aorta, with gentle rotation of the guide catheter aiding this maneuver. A trapping balloon is then used to secure the retrograde guidewire inside the antegrade guide

catheter, facilitating its movement toward the coronary ostium. The catch-it maneuver can be adapted to various anatomical regions, such as the aortic arch or aorta, to optimize alignment. A variation of this technique involves using the left coronary cusp to deflect the retrograde guidewire into the same guide in ipsilateral access cases [96].

8. **Antegrade microcatheter probing technique**
   In antegrade microcatheter probing (AMP) after retrograde guidewire crossing, the retrograde MC is advanced inside the antegrade guide catheter, followed by the removal of the retrograde guidewire and intubation of the microcatheter with an antegrade guidewire for rapid antegrade conversion [97]. AMP is indicated when guidewire externalization is not desired, for example, when crossing epicardial collaterals or when an externalization guidewire is not available. It also avoids a second microcatheter within the same guide in ipsilateral retrograde CTO-PCI.

Step 10: The retrograde gear removal

After the completion of PCI, the retrograde microcatheter is readvanced into the antegrade guide, unless resistance is encountered. It must protect the CC until the soft wire tip is back in the CC. Both antegrade and retrograde guiding catheters are slightly disengaged from the coronary ostium to avoid ostial dissection because of externalized wire retraction (antegrade guide is disengaged by pushing the externalized wire and the retrograde guide by fixing the microcatheter using it as rail for guide retraction). After establishing guiding catheter control, the externalized wire is withdrawn gradually synchronized with the heart beat taking care not to kink it. Then the retrograde microcatheter is withdrawn into the donor vessel leaving the retrograde wire in the CC. The dye is injected into retrograde guide to ensure that there is no injury to the CC [98]. If there is good CC flow, the microcatheter is readvanced across the CC to facilitate safe removal of wire.

Table 11.4 **Complications of retrograde CTO PCI: prevention and bailout**

Complications	Prevention	Bailout
CC perforation	• Careful manipulation of wire • Verification of wire position before microcatheter advancement • No dilatation of epicardial CC	• Prolonged balloon inflation • Pericardiocentesis if required • Sealing of both antegrade and retrograde epicardial CC • Septal hematoma are usually benign • Anticoagulation reversal after removal of all coronary equipment
Donor vessel guide-induced dissection	• Maintenance of workhorse wire in donor vessel • Retrograde guide position and waveform monitoring • Disengagement of retrograde guide during advancement of antegrade equipment	• Stenting of dissection
Donor vessel thrombosis	• Adequate flushing • ACT (350 seconds or more)	• Thrombus aspiration • Stenting
Periprocedural MI	• Avoidance of large SB dissection • ACT 350 seconds or more	• Continuous monitoring • Treatment of ischemia • Low threshold for stenting • Consideration for alternative CC

ACT, activated clotting time; CC, collateral channel; CTO, chronic total occlusion MI, myocardial infarction; PCI, percutaneous coronary intervention; SB, side branch.
Source: Adapted from [100].

Complications of the retrograde approach

The risk of complications is higher with the retrograde approach than with the antegrade-only method. In a meta-analysis [99], the longer retrograde CTO PCIs were longer, associated with higher contrast volume and fluoroscopy time as well as a higher risk of complications like contrast-induced nephropathy, pericardiocentesis, and periprocedural MI. According to the same study, over a 4-year period, retrograde CTO PCI was linked to worse long-term outcomes, such as MI, target lesion revascularization, and target vessel revascularization, than antegrade PCI. Table 11.4 lists common problems with the retrograde method [100].

1. **Donor vessel troubles**
   Guide-induced dissection could result from the antegrade equipment delivery across the externalized wire. Disengaging the retrograde guide during this stage is therefore essential. In the event of dissection, the donor artery needs to be stented. Because CTO PCIs usually include a longer procedure with equipment in the donor vessel, they are more prone to donor vessel thrombosis. After removing any equipment, it is imperative to make sure there is adequate flushing and back bleeding. ACT should be monitored at least every 30 minutes to maintain a target of more than 350 seconds. In certain situations, aspiration thrombectomy and additional heparin may be necessary.
2. **CC perforation**
   Most of the time, septal CC perforations seem to be benign and do not need to be treated further. Even yet, there have been sporadic reports of tamponade and septal hematomas [101, 102]. Epicardial CC perforations may lead to fatal tamponade and warrant immediate treatment by sealing both sides of the perforation usually with coils, thrombin, or subcutaneous fat [103]. Patients who have had coronary artery bypass graft surgery in the past may develop difficult-to-treat loculated hematoma and dry tamponade as a result of their perforations [104].

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CHAPTER 12

Ostial Lesions

Debabrata Dash, Gautam Kumar, Moo-Hyun Kim, Duong Hoang Ngoc Thao, My Tra Mai, Trung Le Dinh, Marco Zuin, and Thach N. Nguyen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
🌢, low risk of complications; 🌢🌢, high risk of complications

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CHALLENGES

Ostial lesions are characterized as those located within 3 mm of the vessel ostium at the aorto-ostial or branch-ostial junction. These lesions display distinct pathologic and morphologic/angiographic features, making them a particularly challenging subset associated with worse outcomes compared to nonostial lesions. Typically, ostial lesions contain higher amounts of calcium and fibrous tissue and exhibit a greater tendency for elastic recoil [1, 2]. Additionally, ostial lesions are prone to increased intimal hyperplasia following stenting.

Percutaneous coronary intervention (PCI) for aorto-ostial lesions presents several challenges, including (1) difficulty in engaging the lesion with the guide and inadequate guide support; (2) ischemia caused by pressure dampening; (3) aorto-coronary dissection; (4) risk of guide and equipment dislodgement, which may require guide extensions for retrieval; (5) geographic miss, resulting in either incomplete coverage of the vessel ostium or significant stent protrusion into the aorta, necessitating further stenting or leading to higher restenosis rates; and (6) stent deformation proximally due to vessel size mismatch or guide manipulation [3] (Table 12.1).

Even in the era of drug-eluting stents (DES), the ostial location continues to be associated with worse outcomes. The unique location of these lesions presents significant challenges for the operator, including limited angiographic views, highly variable ostial anatomy, unstable guide support, exaggerated cardiac motion, and often considerable myocardium at risk. It is crucial to rule out catheter-induced ostial vasospasm, which is commonly present, before proceeding with intervention.

Table 12.1 Treating Ostial Lesions: Challenges and Solutions

Challenge	Solution
1. Determining functional significance (aorto-ostial lesions)	• Ensure that the guide is disengaged, as pressure dampening could artificially increase fractional flow reserve measurements
2. Inability to engage (aorto-ostial lesions)	• Guide extensions • Advance the guide with a coronary wire preloaded at the tip of the guide so that wiring can occur immediately when the ostium is engaged
3. Pressure dampening (aorto-ostial lesions)	• Use a smaller guide or a guide with side holes (side-hole guides should never be used to engage unprotected left main arteries). In general, for ostial LM lesions, Judkins left guides may be preferred over extra-backup guides • Keep the guide disengaged from the vessel ostium when not moving equipment within the coronary artery • Do not inject when pressure is dampened (to minimize risk for dissection)

(*Continued*)

Table 12.1 (Continued)

Challenge	Solution
4. Difficulty with stent placement	• Use the "two-hand technique": the right hand handles advancement and withdrawal of the balloon/stent, while the left hand moves the guide • Use of multiple projections to ensure the stent is optimally positioned **before** deployment • Insertion of a second wire to mark the position of the aortic root • Szabo technique (using an anchor wire over the proximal strut of the stent) • Devices designed to facilitate aorto-ostial stent placement, such as Ostial Pro
5. Inability to engage ostium after stent delivery (aorto-ostial lesions)	• Minimize stent overhang in the aorta • Ostial flaring by inflating a balloon halfway in the stent and halfway in the aorta • Devices specific for flaring an aorto-ostial stent, such as the Flash Ostial System
6. Suboptimal stenting result	• IVUS to detect stent underexpansion, incomplete ostial coverage, or other abnormalities • High-pressure balloon inflations or laser to expand under-expanded stents; meticulous pre-stenting lesion modification (balloon, atherectomy, etc.) for preventing under-expansion • Additional stent implantation if ostium is not covered
7. Donor vessel compromise (branch ostial lesions)	• Wire in donor vessel • Fractional flow reserve to determine severity of the stenosis • Post-dilatation ± stent placement

Source: [12] / Europa Group

SHARP THINKING

Strategic Concerns for PCI of Ostial Left Anterior Descending and Left Circumflex

Interventions in ostial left anterior descending (LAD) or left circumflex (LCX) lesions pose many concerns:

1. The balloon or stent may impinge on the origin of the non-dilated artery, potentially obstructing flow.
2. Acute occlusion could significantly jeopardize cardiac function or survival.
3. A vessel size discrepancy between the left main (LM) and the LAD or LCX may occur.
4. Dissection in the proximal LAD or LCX could extend retrogradely into the LM segment.
5. Restenosis at the proximal end of the stent may lead to restenosis of the LM.
6. Antegrade or retrograde embolization can occur, potentially affecting the other artery (from LAD to LCX or vice versa, from LAD to LM, or leading to systemic embolization).

GUIDE

A guide that maintains stable alignment with the vessel's axis at the ostium, without a tendency to dive into the vessel, is preferred. The interventional device, particularly the stent, should remain in a stable position while the operator adjusts the guide into or away from the ostium.

Typically, Judkins-type guides (some with a short tip) or extra backup/geometric catheters work well for the left coronary artery, while Amplatz-type guides are generally avoided. For certain right coronary artery (RCA) ostia with high takeoff and RCA vein grafts, a multipurpose guide is the most suitable choice.

Tips and Tricks

***Guide selection and positioning** Due to the lesion's proximity to the ostium, the guide should not be fully engaged or deeply seated. A standard Judkins guide may provide sufficient backup support with coaxial alignment without requiring aggressive intubation. While a guide with side holes can be beneficial, the contrast media efflux may obscure the precise location and severity of the ostial lesion. Maintaining coaxial alignment allows the interventional device to be advanced, positioned, and verified with the guide tip just outside the ostium. The Ostial Pro® device further optimizes guide positioning at the ostium [4].

****Disengagement of guides** Once the device catheter – carrying the undeployed stent, balloon, or atherectomy device – is correctly positioned, the guide is gently withdrawn 1–2 cm into the aorta to prevent balloon inflation or stent deployment inside the guide (Figure 12.1). Applying gentle forward pressure on the device catheter or inflating the balloon at low pressure (1–2 atm) can help maintain proper positioning while retracting the guide. Ideally, during predilatation, a "waist" should appear in the center of the exposed balloon, confirming correct placement (Figure 12.1). Frequent test injections are recommended to ensure the guide tip does not inadvertently advance beyond the ostium and that the device remains within its intended area.

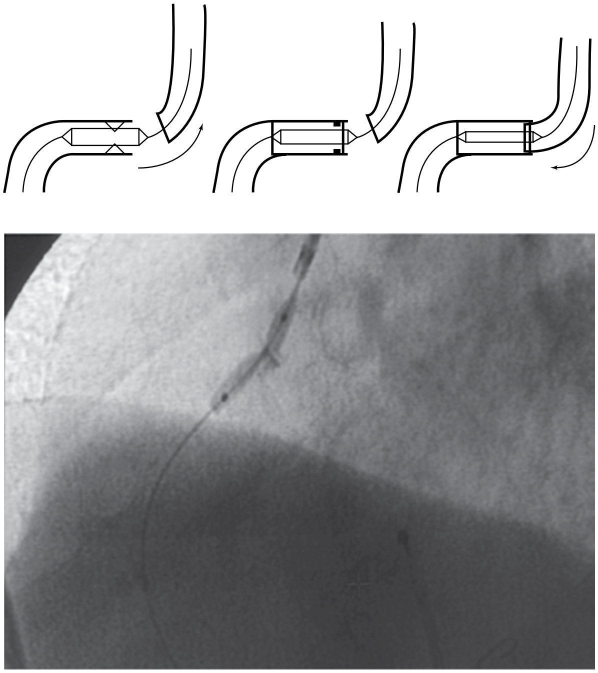

Figure 12.1 The balloon is positioned across the lesion. Next, the guide is withdrawn into the aorta to expose the balloon. After inflation and stent deployment, the deflated balloon can be used to stabilize and "rail in" the guide.

****Re-engagement of guides** After stent deployment, a follow-up angiogram, postdilatation, or additional device use may be necessary. Even with proper guide alignment, re-entering an ostially deployed stent can be challenging. To facilitate re-engagement before the final angiogram, the stent delivery balloon can be used to "rail in" the guide tip (Figure 12.1). Once the stent is deployed, the deflated balloon should remain in place or be advanced slightly. Applying traction to the balloon catheter while carefully advancing the guide tip into the ostium of the stent helps achieve optimal alignment without damaging the stent.

When removing the balloon, traction should first be applied to the guide to prevent forward displacement of the guide into the ostium. After completing the coronary angiogram, the guide can be withdrawn by applying a slight forward push on the wire. This maneuver should be performed under continuous monitoring of the wire tip to prevent distal coronary artery perforation. During postdilatation or intravascular ultrasound (IVUS), careful handling of the deployed stent is essential to avoid damage, dislodgement, or unintended extraction.

****Two-guide technique** Correct positioning of a stent at an ostial lesion can be difficult due to poor visualization once the guide has been backed out of the artery to allow deployment. The simultaneous use of a diagnostic catheter allows optimal visualization of stent position while maintaining a stable guide position well away from the stent. This technique used a second diagnostic catheter to enhance visualization of the lesion during stent positioning [5]. An 8-Fr Judkins right guide was stable and provided good support. However, with the guide in a position that would allow adequate visualization of the lesion, the tip of the guide sat on the lesion, precluding perfect stent deployment. When the guide was withdrawn slightly, visualization was poor and the proximal balloon remained within the guide, risking movement during deployment. A 6-Fr diagnostic catheter was then introduced from the opposite side and engaged, providing excellent visual support for stent positioning.

WIRE

Intermediate-strength wires typically provide sufficient support, as most of the wire is anchored distally in the vessel. Extra-support wires can offer additional stabilization, particularly in ostial saphenous vein graft lesions. To minimize the risk of distal perforation, hydrophilic wires should be avoided, and the wire tip should be closely monitored throughout the procedure. Maintaining a stable wire position can be challenging during device delivery and guide positioning, making continuous vigilance essential.

LESION PREPARATION

While most published data support the feasibility of direct stenting in non-ostial lesions, predilatation should be strongly considered for ostial lesions due to the need for precise positioning. Without pre-dilatation, the operator may encounter significant resistance from the lesion, further limiting angiographic landmarks and increasing the risk of watermelon seeding. Recognizing a poorly yielding or "non-dilatable" lesion in heavily calcified cases before stent deployment is critical to ensuring procedural success.

Tips and Tricks

****Watermelon-seeding effect of aorto-ostial lesions** In patients with ostial lesions, balloon migration – either proximally or distally – can occur during inflation. To minimize this risk, the balloon should be inflated gradually (1 atm at a time) while gently retracting the balloon catheter to prevent distal migration. However, persistent watermelon seeding may still occur. In such cases, using a buddy wire or a cutting balloon (CB) can help stabilize the balloon, particularly in cases of in-stent restenosis (ISR).

BOX 12.1 TACTICAL MOVE

Best Options for Ostial Lesion Pre-dilatation

1.	**No added cost**	**FIRST Best Maneuver**: Inflate the predilation balloon to maximum
2.	**$⧗**	**SECOND Best Maneuver**: Add a second buddy wire and perform focused-force angioplasty [7]
3.	**$$⧗⧗**	**THIRD Best Maneuver: Cutting balloon angioplasty**
4.	**$$$⧗⧗⧗💧**	**FOURTH Best Maneuver:** Atherectomy; consider excimer laser for non-dilatable stent

Non-dilatable Lesion

Due to the increased rigidity and frequent calcification of ostial lesions, complete expansion of the pre-dilating balloon is essential before stenting. If full balloon expansion cannot be achieved at pressures above 18 atm, CB angioplasty or atherectomy should be considered. While routine debulking or CB preparation is not typically recommended, especially in the DES era, these techniques play a crucial role in selected cases to ensure optimal stent deployment.

As with all challenging lesions, IVUS is highly valuable for lesion characterization and facilitating optimal stent placement. When faced with a non-dilatable lesion, selecting the best approach is critical. The BEST maneuver ranking for pre-dilating an ostial lesion is outlined in Box 12.1.

Tips and Tricks

****Atherectomy of ostial lesions** Ostial lesions offer a challenge even to those experienced in atherectomy. This is due to possibly inadequate guide support and lack of coaxial seating. Rotational atherectomy has been most commonly used for this purpose, but in experienced hands orbital atherectomy can have certain unique advantages: the ability to pass the crown distal to the stenosis and ablate in a retrograde fashion back to the ostium, and decreased risk of wire prolapse into the aorta and accidental wire cutting, as the ViperWire Advance™ (Cardiovascular Systems, Inc., St. Paul, Minnesota, USA) is much stiffer than the RotaWire™ Floppy (Boston Scientific, Marlborough, MA, USA) [6].

For aorto-ostial lesions, care should be taken to ensure coaxial alignment of the guide catheter and RotaWire and to avoid wire loops. The guide catheter should be slightly disengaged, and the burring should be started from the inside of the guide catheter. For orbital atherectomy, the crown is advanced distal to the lesion. After disengaging the guide catheter, the ablation is started from the way back (back cutting). Orbital atherectomy has certain unique advantages, such as the ability to pass the crown distal to the lesion and ablate in a retrograde fashion back to the ostium and a decreased risk of wire prolapse into the aorta and accidental wire cutting [6].

STENT

Stent Positioning

Identifying the precise proximal end of an ostial lesion is often challenging. One reason is that the guide cannot be deeply engaged in the ostium or the lesion itself. Since the guide must remain outside the aorta, contrast injection results in partial contrast entry into the ostium while the remainder swirls along the curve of the coronary sinus, obscuring the exact location and severity of the lesion. Additionally, the presence of a device across the lesion during positioning can reduce contrast flow, further limiting visualization of the lesion and ostium. Alternative landmarks, such as a fleck of calcium in the aortic wall, may aid in identifying the ostial entry point. A second wire curving into the coronary sinus can also help prevent deep guide engagement (Figure 12.2). After stent deployment, assessing for geographic miss in the short, ring-like ostial segment left uncovered by the stent becomes even more difficult. A small guide catheter may pass through this segment without causing ventricularization of pressure, and a coronary angiogram may fail to detect abnormalities due to contrast backflow covering the ostial segment. This issue is exacerbated if the ostial segment is imaged in a non-orthogonal projection, as adjacent contrast-filled vessel segments may obscure the short, uncovered portion. In such cases, StentBoost (Philips Medical Systems, Eindhoven, The Netherlands) can be a valuable tool for improved visualization [7].

Tips and Tricks

****Stent positioning with a second wire** Positioning the guide during stenting, particularly for an ostial RCA lesion, can be facilitated by using a second steerable, soft-tipped wire placed in the aorta just below the coronary ostium. This second wire helps stabilize the guide outside the coronary artery, preventing deep engagement into the ostium. Additionally, it serves as a reference point, clearly defining the junction between the coronary artery and the aorta – an important landmark for precise stent placement (Figure 12.2).

*****Double wire in ostial ISR lesion** Engaging a chronic ostial stent, particularly in cases of restenosis, can be challenging. One report describes threading a wire through a protruding stent strut to help stabilize the guide position, followed by advancing a second wire to cross the lesion [8]. However, this technique should be performed with caution, as stent avulsion or migration has been reported during such manipulations [8]. Additionally, a DES may remain at risk of migration for several months post-implantation due to delayed neointimalization or late malapposition.

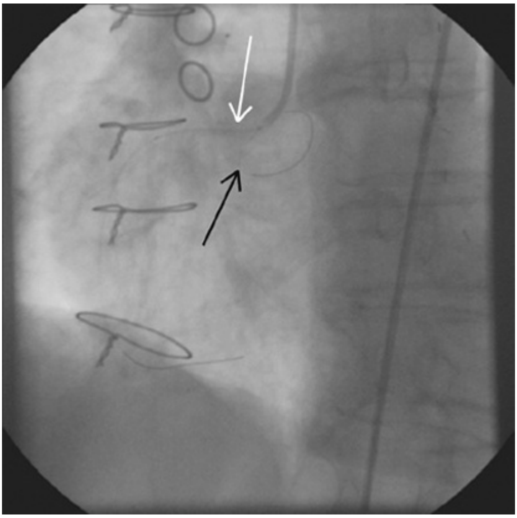

Figure 12.2 A second wire in the aorta helps to outline the sinus of Valsalva and stabilizes the guide at the ostium (black arrow). When backloaded through the last strut, it can also be used to anchor the stent at the ostium (white arrow).

TOP PERFORMANCE

Stent Positioning with an Anchor Wire: The Szabo Technique

This technique addresses angiographic and cardiac motion-related challenges by anchoring the stent for precise positioning. A second wire is placed in the aorta, with its soft distal tip outlining the ostium. This wire is then backloaded through the most proximal stent strut. As the stent is advanced across the lesion, the second wire anchors the proximal strut just outside the aorto-ostial junction (Figure 12.3).

For ostial side branches (SBs), this method helps optimally position the proximal end of a stent at the LAD ostium [9, 10]. In LCX stenting, the anchor wire is positioned in the LAD. Studies have reported this technique as a feasible approach, yielding good angiographic and clinical outcomes in larger series [11–13]. However, it is associated with a steep learning curve and potential complications, including stent dislodgement. Recent data indicate that even this technique does not ensure "perfect" positioning [14]. To minimize stent deformation and dislodgement, key precautions include the following:

- Avoiding partial inflation of the stent while preparing the anchor strut.
- Using the floppy portion of the anchor wire.
- Removing the anchor wire only after fully deflating the stent balloon, following an initial low-pressure deployment and a final high-pressure inflation.

Other potential issues include wire entanglement, inability to advance the stent across the lesion, and stent dislodgement.

Tips and Tricks

*****How to advance the side-branch wire if the wire is twisted** If the SB wire becomes twisted, gently retract the entire system slightly and then re-advance the stent without twisting (Figure 12.4). Alternatively, a microcatheter can be used to straighten the SB wire. Advance the microcatheter as far as possible, then re-wire the SB (Figure 12.5).

*****How to reposition the stent** If the position of the stent is not optimal and it needs to be repositioned, pull the SB wire up to its soft part and then reposition the stent by advancing it or withdrawing it. Because the stent is secured on the soft part of the SB wire, the stent can be moved without pulling the SB wire (Figure 12.6).

Stent Deployment

Once the stent is positioned across the lesion, the guide should be slightly withdrawn while maintaining gentle forward pressure to fully expose the balloon stent from the guide. Inflating the balloon while it is partially within the guide can lead to balloon rupture. Using anatomical landmarks, such as a calcium deposit in the aorta, can aid in precise positioning during these maneuvers. Contrast injections at this stage may help outline the sinus of Valsalva, and asking the patient to hold their breath can further stabilize positioning. If significant motion is present, low-pressure inflation (1–3 atm) can provide additional stabilization, allowing for final stent position adjustments if needed [15]. Careful manipulation is crucial, particularly when repositioning the stent catheter in heavily calcified lesions or withdrawing it into the guide, as there is a risk of the stent stripping from the balloon. To prevent lesion recoil at the stent edge, the stent should be positioned with 1–2 mm protruding into the aorta. Very short stents (<12 mm) should be avoided to ensure adequate anchoring and distal lesion coverage.

Stents should be appropriately sized (1,1 vessel-to-stent ratio) and deployed at high pressures (≥12 atm) for optimal apposition. Typically, a second high-pressure inflation is performed with slight retraction of the stent balloon, ensuring full ostial apposition while minimizing the

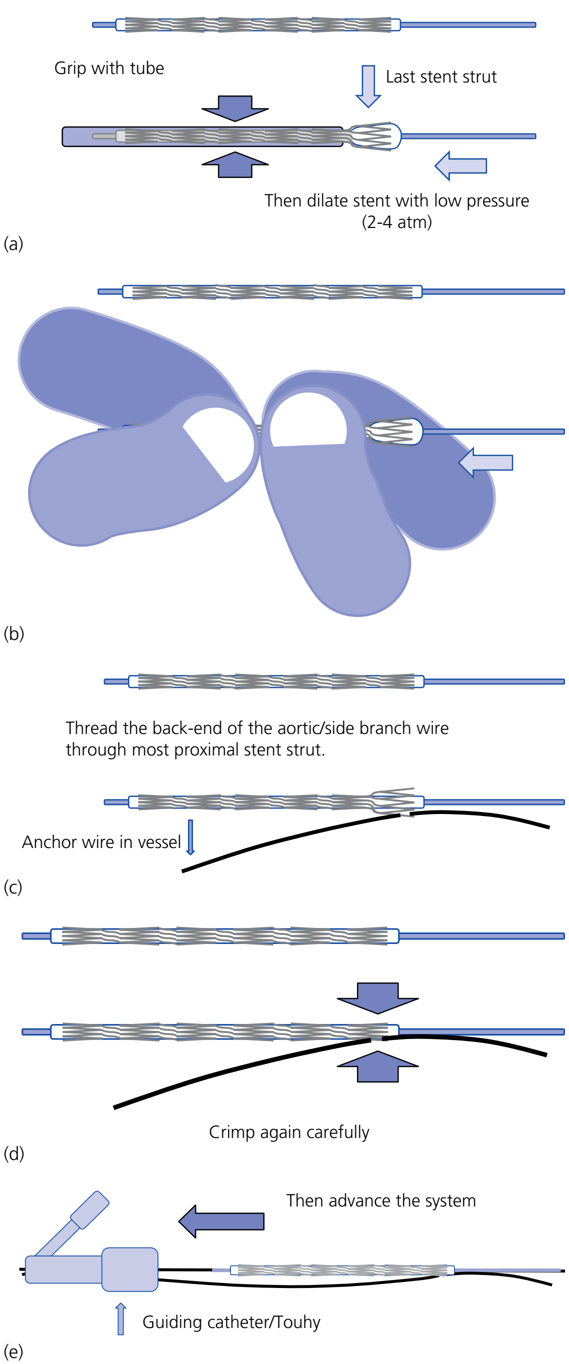
Grip with tube
Last stent strut
Then dilate stent with low pressure
(2-4 atm)
(a)
(b)
Thread the back-end of the aortic/side branch wire
through most proximal stent strut.
Anchor wire in vessel
(c)
Crimp again carefully
(d)
Then advance the system
Guiding catheter/Touhy
(e)

Figure 12.3 (a) Grip the stent with a tube or using the fingers. (b) Then dilate the proximal end of the stent at a low pressure (4–6 atm). (c) After deflation, advance the SB wire through the most proximal strut or backload the SB wire if the tip of the wire has already been advanced far into the SB. (d) Crimp the proximal end of the stent carefully again. (e) Then advance the whole system into the guide over both the primary wire and the anchor wire.

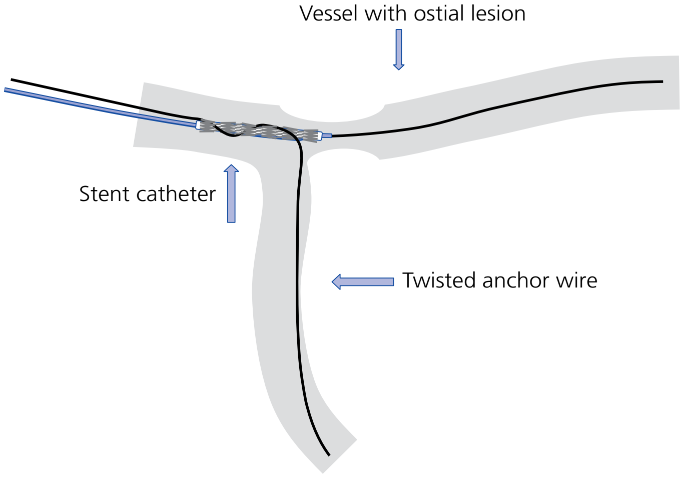

Figure 12.4 How to advance the side-branch wire if the wire is twisted.

risk of distal edge injury. Excessive traction on the balloon should be avoided, as it may cause the stent to retract and displace into the aorta. Routine post-dilatation with larger balloons and ostial "flaring" of the stent, while commonly performed, is likely unnecessary and should be weighed against the risk of potential intramural dissection of the aorta.

DEDICATED EQUIPMENT

The Flash Ostial System

The Flash Ostial System (Ostial Corp., Campbell, CA, USA) is a dual-balloon angioplasty catheter (Figure 12.7) consisting of the following:

- A larger proximal low-pressure balloon (anchoring balloon).
- A higher-pressure distal balloon (angioplasty balloon).

It features three fluoroscopic markers to assist with precise positioning:

- Proximal marker – Identifies the proximal end of the anchoring balloon, which should be positioned in the aorta.
- Middle marker – Indicates the proximal end of the angioplasty balloon and should be aligned with the vessel ostium.
- Distal marker – Marks the distal end of the angioplasty balloon.

The distal balloon is available in sizes 3.0, 3.5, 4.0, and 4.5 mm (length: 8 mm) and 5.0 mm (length: 12 mm) for use as a rapid-exchange system over a 0.014-inch guidewire. The proximal anchoring balloon can expand up to 14 mm. Inflation is controlled separately:

- The distal balloon is inflated using a standard inflation device.
- The proximal balloon is inflated with a 1-mL syringe containing 0.4 mL of saline/contrast mixture (Figure 12.8).

Following stent implantation, the overhanging portion of the deployed stent can be flared with this device, which may improve stent apposition at the aorto-ostial lesions (AOL) landing site and facilitate future catheter re-engagement. Naturally, the device does not prevent geographic miss, but usually a longer DES can be implanted for adequate lesion coverage because the overhanging portion of the stent (~1 mm) will eventually be flared [15].

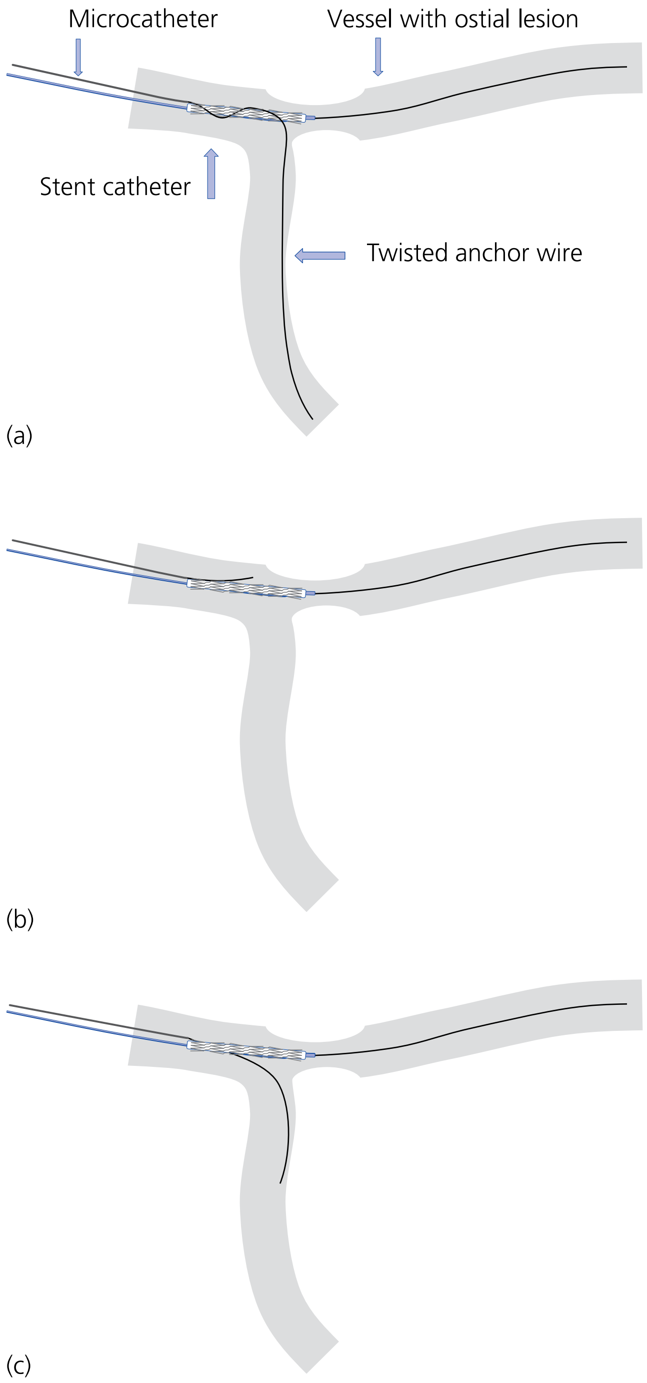
Microcatheter
Vessel with ostial lesion
Stent catheter
Twisted anchor wire
(a)
(b)
(c)

Figure 12.5 Using a microcatheter to straighten the side-branch wire.

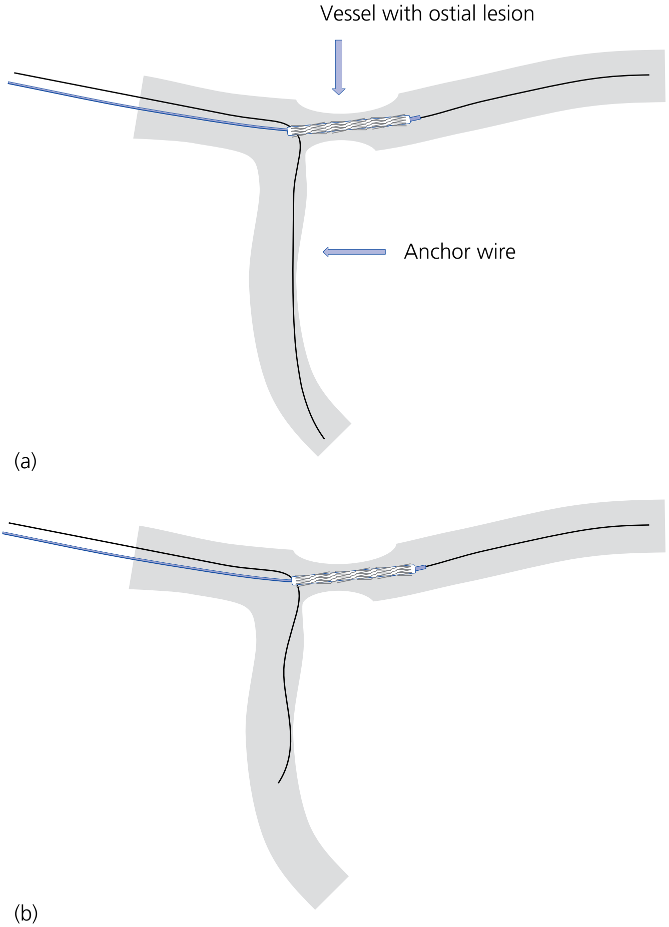

Figure 12.6 (a,b) To advance the stent a little bit further, pull back the side-branch wire as far as the soft part.

Ostial Side-branch Stenting

Stenting every ostial lesion may not be feasible or necessary, particularly in various clinical and anatomical scenarios, including smaller SBs. In such cases, CB angioplasty offers a safe and effective alternative [15].

Tips and Tricks

***Can we have perfect positioning of a stent for side-branch ostial lesions?** A stent can be precisely positioned and deployed only when the angle between the SB and the main branch is close to 90°. If the angle deviates significantly from perpendicular, the proximal end of the stent may either protrude into the main branch lumen or be positioned too far inside the SB, leaving the ostium uncovered. In such cases, the operator should carefully assess the anatomy of the parent vessel and consider appropriate bifurcation techniques to ensure optimal stent placement.

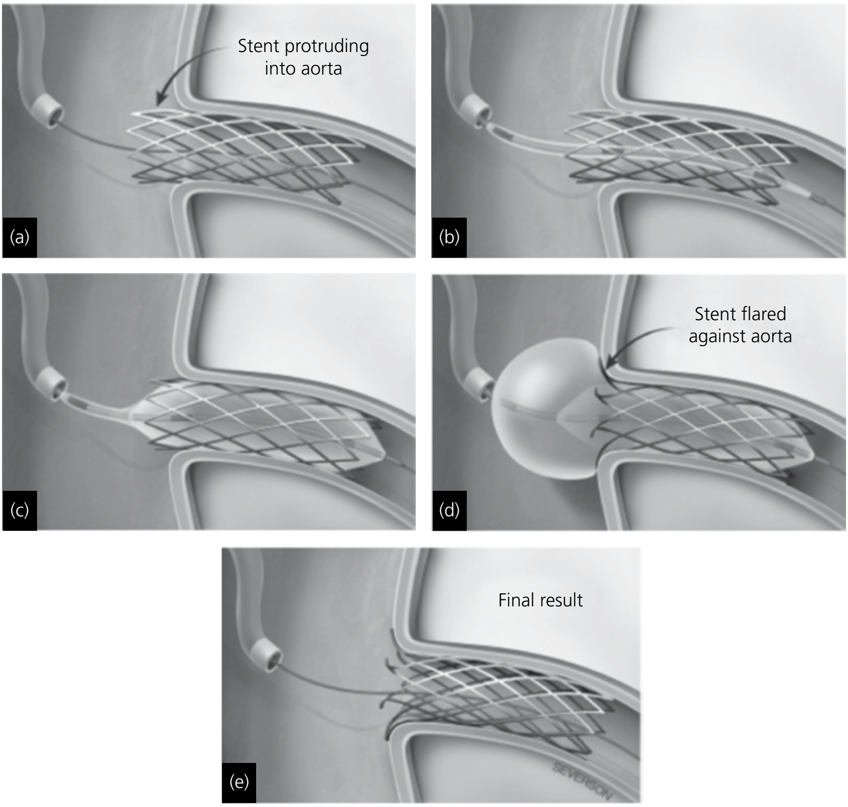

Figure 12.7 Illustration of the mechanism of action of the Flash Ostial System dual-balloon angioplasty catheter. (a) The stent is positioned with the proximal end protruding 1 mm from the vessel ostium. (b) The Flash Ostial System is positioned with the proximal marker in the aorta outside the guide, the middle marker at the ostium, and the distal marker inside the stent. (c) The distal balloon is inflated inside the stent with an inflating device, then (d,e) the proximal balloon is inflated with a 1-mL syringe to flare the stent struts against the aorta. Source: Reproduced with permission from [9] / John Wiley & Sons.

****Stent pull-back technique** For branch ostial lesions, inflate a small balloon at low pressure in the parent vessel, then carefully pull back the stent to the ostium of the SB, ensuring that the balloon in the main branch is slightly compressed. This technique reduces the risk of ostial miss and minimizes the need for additional stents [16].

****Marker wire technique** In this technique, another wire is placed in the main vessel, acting as a marker at the carina that ensures approximate placement of the ostial stent. It is critical to position the proximal radio-opaque marker of the stent proximal to the ostium at the level of the marker wire, which indicates the carina [17].

*****Cutting balloon angioplasty of a “jailed” side-branch ostial lesion** When traditional plain old balloon angioplasty (POBA) fails to adequately dilate an ostial lesion, a CB may be cautiously considered. In a case reported by Hongo and Brent [18], repeated attempts with POBA were unsuccessful when attempting to dilate an ostial lesion through the side

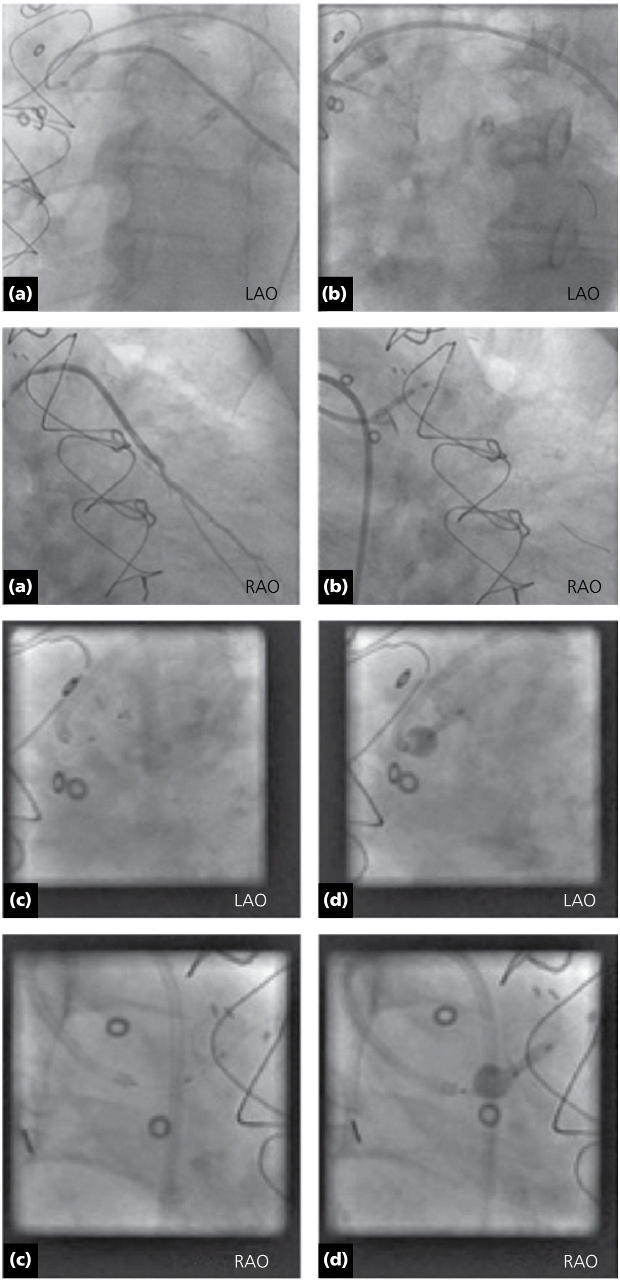

Figure 12.8 (a,b) Flash Ostial balloon usage in upper panel (LAO) and lower panel (RAO) views. The patient is a 67-year-old male who had a coronary artery bypass graft 16 years ago and now presents with unstable angina. Angiography revealed a significant ostial SVG-D1 lesion (panel a). This was stented with a 3.0 × 18 mm DES (panel b). (c,d) The Flash Ostial device was positioned with the proximal marker in the aorta outside the guide, the middle marker at the ostium, and the distal marker inside the stent (panel c). The distal balloon was inflated inside the stent with an inflating device (panel d), then the proximal balloon was inflated with a 1-mL syringe to flare the stent struts against the aorta (panel d), and the distal balloon was inflated followed by the proximal balloon (panel d).

struts. A CB was then introduced, ensuring that its proximal segment remained well within the main vessel lumen, and inflation was performed, achieving excellent results.

*****Tryton dedicated bifurcation stent** For bifurcation lesions where there is no significant disease beyond the SB ostium, a Tryton stent may be deployed in the SB, followed by the placement of a DES in the main branch, with final kissing balloon inflation. This strategy is effective for bifurcation lesions that do not extend significantly into the SB.

ADVANCED AND EXOTIC TECHNIQUES

If achieving a coaxial guide position is difficult due to ostial stent protrusion, the guidewire may inadvertently pass through the side of a stent cell [19]. This issue may not be immediately apparent but can cause significant difficulty when advancing balloons or stents, as increased resistance will be encountered at the level of the protruding stent cell near the ostium. The double-wire technique has been described as a solution to anchor the guide. In this approach, the first wire stabilizes the guide while a second wire is introduced into the true lumen of the stent. However, this can be challenging, as withdrawing the guide to create space for the second wire may cause the guide to move upward, increasing the angle between the guide and the protruding stent lumen, further worsening malalignment. A modified version of this technique has been proposed to facilitate easier engagement and wiring of the true stent lumen [19].

A lack of coaxial guide positioning is often due to the guide being positioned too anteriorly or posteriorly relative to the protruding stent struts. In such cases, the wire frequently passes through the side of a stent cell, which may be difficult to detect in certain projections. This issue typically becomes apparent when significant resistance is encountered while advancing a balloon into the ostium of the stent, accompanied by backward and outward movement of the guide – commonly referred to as "kicking the guide out." To address this, the double-wire technique can be used to anchor the guide. The essential step in this method involves using a deflated balloon (with mild forward pressure) to facilitate controlled pushback, or "kick out," of the guide. This maneuver creates a small gap between the catheter and the protruding stent ostium. By simultaneously applying forward push, traction, or rotation of the catheter, the operator can adjust both the guide's height and angle of engagement. This dual-force approach – where the balloon advances to separate the guide while the guide itself is manipulated to optimize positioning – allows for precise control. Once the guide position is optimized, a second wire, preferably with a soft, flexible tip and an aggressive bend, is introduced into the true lumen of the stent using a loop technique. Multiple fluoroscopic views may be required to determine the optimal angle for wire engagement. After successful engagement, the balloon and first wire are removed, and the procedure continues over the second wire, which now accesses the true lumen through the ostium of the protruding stent.

This technique is also useful for addressing peripheral and coronary aorto-ostial disease [19]. However, the operator must carefully select the balloon size in relation to the stent cell size to prevent complications. Threading a small balloon through a large stent cell (such as in large coronary or peripheral stents) could lead to stent deformation during dilatation. Additionally, excessive forward pressure may distort or compress the stent, making repeat cannulation more challenging. Extra caution is required when pushing the balloon against the side struts of the protruding stent, particularly when using extra-support guiding catheters, as this could result in stent deformation (Figure 12.9).

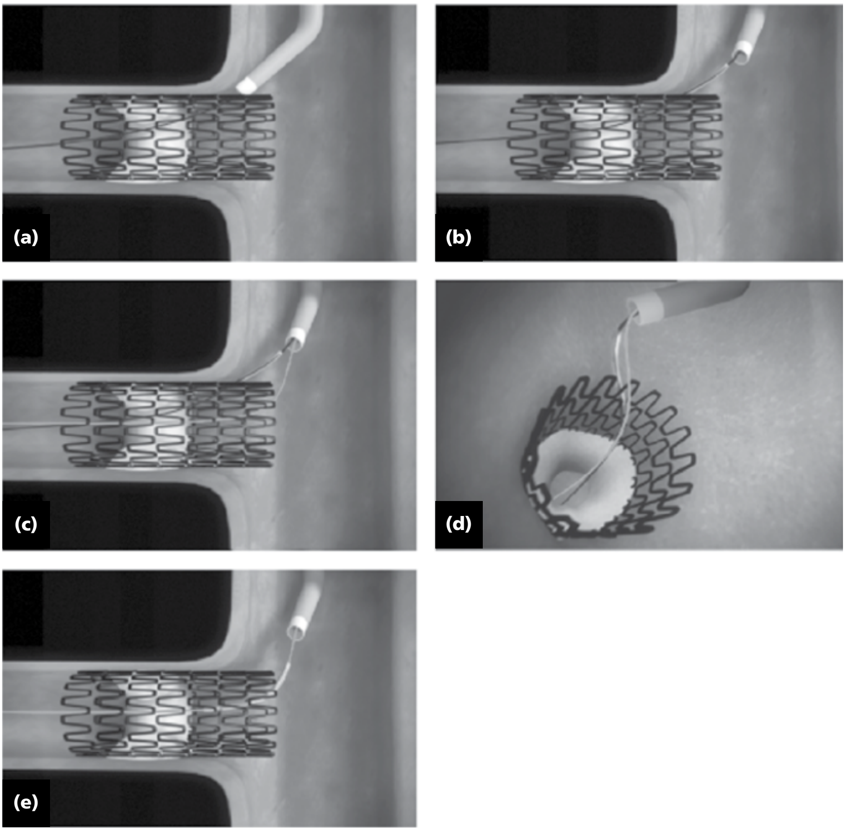

Figure 12.9 Three-dimensional schematic representation of the balloon-assisted in protruding stent technique. (a) The first guidewire is passing through the side of the stent cell. (b) A deflated balloon is used to push the guide catheter back away from the stent. (c,d) A second guidewire is then advanced into the true lumen of the stent. (e) After removal of the first guidewire and balloon from the artery, the second guidewire is located in the true lumen and is used to complete the procedure.

PCI of Ostial ISR Lesion Through Side Strut

In a case report by Burstein et al. [20], multiple attempts with different guides and wires failed to engage the protruding stent in a coaxial fashion, suggesting deformation of the intra-aortic segment of the stent struts. After unsuccessful efforts to achieve proper guide alignment, a 6-Fr Amplatz Right guide catheter was positioned over the protruding stent segment. A Whisper® wire was then advanced through the struts of the aorto-ostial stent and successfully navigated into the distal RCA. To widen the side struts, a 1.5 × 14 mm Maestro® balloon was initially inflated. This was followed by sequential balloon dilations using progressively larger Maestro balloons – 2.0 × 14 mm, 2.5 × 14 mm, 3.0 × 14 mm, and 3.5 × 14 mm – each inflated up to 18 atm. Ultimately, a 3.0 × 16 mm DES was successfully advanced through the widened side struts and deployed at 16 atm, ensuring 1–2 mm of the proximal stent segment protruded into the aorta to achieve full coverage of the RCA ostium. The fully expanded Taxus™ stent displaced the aortic segment of the previously placed stent inferiorly, effectively creating a new entry point into the artery. This technique resulted in an excellent angiographic outcome, successfully restoring access to the RCA while maintaining optimal stent positioning.

Rotablation of Stent-Jailed Side-Branch Stenoses

In a report of jailed SB stenosis, the patients underwent rotational atherectomy, which was performed in the SB and frequently in the parent vessel using a "stepped burr" approach over a rotational atherectomy wire (RotaWire Floppy or RotaWire Extra Support). Following debulking with rotational atherectomy, adjunctive balloon angioplasty was performed on all lesions. Frequently, revascularization of the parent vessel was also performed with the use of simultaneous balloon inflations in the parent and SB vessels (i.e. "kissing balloon" technique) in most cases. Rotational atherectomy was not performed in the setting of acutely stent-jailed SB stenosis. Despite the high procedural success rate, repeat revascularization was common in the study. The target vessel revascularization rate of 44.8% undoubtedly reflects the unfavorable impact of variables such as small vessel size, ostial location, and high incidence of previous revascularization of the treated SBs [21].

Tips and Tricks

*****Rotablation through stent struts** An important technical consideration when using rotational atherectomy to treat SBs covered by stents is the importance of ensuring that the SB has been well dilated through the side struts. This may facilitate passage of the burr and reduce the potential of "burr entrapment." Another concern is the embolization of metallic particles during rotablation. However, there were no cases of periprocedural myocardial infarction following angiographically successful revascularization of SBs with rotational atherectomy, suggesting that rotational atherectomy through the sides of stents can be performed safely.

*****Extraction of stent by cutting balloon at ostial lesion** The CB is designed with blades mounted along its length, which protrude outward upon inflation. During deflation, a gradual rewrapping mechanism folds the balloon into multiple wings over the blades. However, during this rewrapping process, a recess with an acute angle can form between the balloon and the blades. This recess may snag on the stent struts, potentially preventing CB withdrawal. If excessive force is applied to retrieve the CB, it can dislodge or partially pull out the stent. During withdrawal, the force exerted on the balloon catheter is not parallel to the vessel axis, leading to the formation of an anchoring point where the stiff proximal edge of the blade meets the soft proximal balloon catheter. This anchoring point is particularly prone to catching on proximal stent struts, especially at the orifice of the RCA, where the proximal RCA forms an almost 90° angle with the aortic wall. To prevent this complication, the CB should first be advanced slightly after deflation before being gently withdrawn. Other potential risks include stent strut fracture caused by the microblades or an underexpanded stent with inadequate strut apposition, which may create additional catching points [20].

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CHAPTER 13

Acute ST-segment Elevation Myocardial Infarction

Thuong Dzung Ho, Marco Zuin, Quan H. Nguyen, Alan Fong, Huan Dat Pham, Linh N. Luu, Hoang Anh Tu, Tuan T. Nguyen, Dang Cong Tran, Nguyen Thi Huong, Le Cao Phuong Duy, and C. Michael Gibson

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Acute ST-segment elevation myocardial infarction (STEMI) typically results from the acute occlusion of a major epicardial coronary artery, often due to the rupture of an atherosclerotic plaque, in the absence of sufficient collateral blood flow from other coronary territories. Timely, complete, and sustained reperfusion of the infarct-related artery (IRA) is crucial for reducing infarct size, preserving left ventricular (LV) function, and lowering mortality rates. This reperfusion helps restore normal myocardial perfusion, which is essential for minimizing the damage caused by STEMI.

URGENT CORONARY ANGIOGRAPHY

First, the IRA should be identified using a 12-lead electrocardiogram (ECG). Subsequently, different views of the presumed non-IRA should be obtained using a diagnostic or guide catheter capable of performing both left and right coronary angiography via the transradial approach [e.g. Tiger (Radiofocus Optitorque 5F; Terumo Europe N.V., Leuven, Belgium), Kimny (Boston Scientific, Natick, MA, USA), or Amplatz left (Boston Scientific, Maple Grove, MN, USA)]. This step is crucial to evaluate the extent of disease in the coronary artery supplying the non-infarcted myocardium and to assess collateral flow, if present, to the distal segments of the IRA. Angiography of the presumed IRA should then be performed with a guide

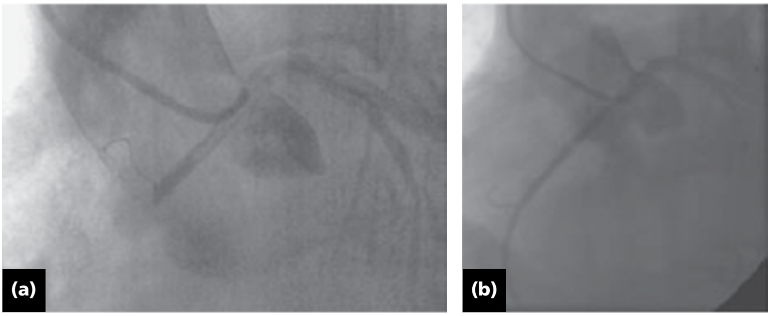


Figure 13.1 The patient arrived with typical angina and ST-segment elevation in leads 2, 3, and aVF. The LAD showed one moderate lesion in its mid-segment. The RCA was not visualized, even with the aortogram. (a) The RCA is found to be in its usual location, where it originates from the left sinus, anterior and superior to the LM ostium with TIMI 0 flow: no antegrade flow. The missing RCA is the IRA. (b) The patient successfully underwent PCI of the artery and achieved strong and brisk (TIMI 3) flow.

to enable prompt initiation of percutaneous coronary intervention (PCI). The culprit lesion must be clearly identified and characterized based on parameters such as diameter stenosis, angiographic evidence of thrombus, and epicardial thrombolysis in myocardial infarction (TIMI) flow grade (Figure 13.1a). During diagnostic angiography, all major vessels and their large branches should be thoroughly evaluated to avoid missing the IRA (Figure 13.1b). Routine left ventriculography is not necessary; however, if assessing LV dysfunction is required, a pigtail catheter can be used to measure LV end-diastolic pressure (LVEDP).

SHARP THINKING

When to Use the Radial Approach

Numerous large, randomized trials have demonstrated the mortality benefits of an upfront radial approach in STEMI patients [1], including significant reductions in bleeding and vascular complications. While radial access should be considered for all patients undergoing primary PCI, it is particularly advantageous for those at high risk of bleeding. However, caution may be warranted in patients with anatomical challenges, such as a tortuous subclavian artery, which are more common in women, older individuals, those with hypertension, or those of shorter stature.

WARNINGS

High-risk Patients

High-risk patients should be promptly identified based on clinical evaluation, hemodynamic measurements (e.g. heart rate, rhythm, arterial pressure, and LVEDP when necessary), and coronary anatomy. In the emergency setting, patients presenting with a heart rate below 100 bpm and blood pressure above 100 mmHg generally have very low in-hospital mortality rates [2]. Key factors for identifying high-risk patients are summarized in Box 13.1.

If pulmonary edema fails to respond promptly to pharmacologic treatment, endotracheal intubation and mechanical ventilation become essential. In these critical situations, the involvement of a physician-intensivist is recommended. This allows the interventional cardiologist to concentrate on performing the PCI while ensuring that comprehensive medical and supportive care is effectively managed.

QUICK DECISIONS

How Many Arterial and Venous Accesses Do We Need?

Patients experiencing electrical instability, such as bradycardia with or without heart block, may necessitate temporary pacemaker placement, making femoral venous access advisable in these cases. For patients presenting with cardiogenic shock, establishing multiple access points upfront is crucial. This typically involves securing two arterial sites, with at least one being femoral, and placing a central venous line. Delaying these interventions risks further patient deterioration, complicating successful arterial cannulation as vessels constrict and lose pulsatility. Having ultrasound equipment readily available is beneficial, as it can facilitate rapid and precise cannulation, especially in challenging cases, and has been linked to reduced access times and bleeding rates.

BOX 13.1 THE FACTORS IDENTIFYING HIGH-RISK PATIENTS

1. >70 years of age
2. Ejection fraction <45%
3. Multivessel disease
4. Suboptimal PCI
5. Persistent arrhythmia
6. Blood pressure <100 mmHg and heart rate >100

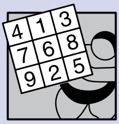
PRIMARY PCI

After defining the coronary anatomy and clinical evaluation of the patient, primary PCI should be attempted if the IRA has a significant stenosis or thrombus with inadequate epicardial flow (TIMI <3). The exclusions for primary PCI are listed in Box 13.2.

BOX 13.2 ANGIOGRAPHIC EXCLUSIONS PRECLUDING PERFORMANCE OF PRIMARY PCI

1. Unprotected LM >60% (only for US operators)
2. IRA with stenosis <70% and with TIMI 3 flow
3. IRA supplies a small area of myocardium: risk versus benefits
4. Inability to clearly identify the IRA
5. Asymptomatic patient with multivessel disease with TIMI 3 flow, and CABG is indicated

GAME PLAN



Before initiating PCI, selecting a guide with adequate coaxial alignment is essential to ensure good support. If the IRA opens after wire passage and the distal segments are clearly visualized, direct stenting of the culprit lesion may be considered. However, this technique is generally not recommended for tortuous vessels, bifurcations, or complex lesions due to potential complications. A potential drawback of direct stenting is stent undersizing, which can occur if the distal segment of the IRA is inadequately visualized due to residual stenosis or chronic spasm

(*Continued*)

from low flow. To mitigate this risk, balloon pre-dilatation using an undersized balloon (e.g. 2.5 mm) is often recommended. If the patient is not hypotensive, administering intracoronary nitroglycerin (100–200 µg) can help better define the IRA's size and diameter by dilating the distal arteries. This allows for more accurate selection of the stent diameter and length, aiming for a stent-to-artery ratio of 1:1. Oversizing the stent can lead to complications such as edge dissection, distal microvascular embolization, and vasospasm due to an α-adrenergic "storm."

Careful attention must be paid to ensure complete coverage of the culprit plaque and any residual intimal dissection. For bifurcation lesions involving a significant side branch (>2 mm), protecting the side branch with an additional wire before stenting (using the trapped wire technique) is advisable. In cases where plaque shift results in significant ostial stenosis or occlusion after stenting the main vessel, exchanging wires and performing a final "kissing balloon" inflation is recommended.

Systematic side-branch stenting using techniques like "T, V, Y, culotte, and crush" should generally be avoided, as it does not reduce restenosis rates and may increase the risk of subacute stent thrombosis. At the conclusion of the procedure, obtaining two orthogonal views of the stented segment is essential to confirm an optimal angiographic outcome. Following stent deployment, it is advisable to avoid rapid balloon deflation to prevent a sudden "vacuum effect," which can dislodge thrombi. This precaution is particularly important for lesions with a heavy thrombus burden, as rapid deflation could exacerbate the risk of thromboembolic complications.

Primary PCI Without On-site Surgical Backup

PCI can be performed in the hospital without on-site surgical backup if the criteria detailed in Box 13.3 are fulfilled [1].

Primary Balloon Angioplasty Without Stenting

It is crucial to recognize that not all lesions require stenting. If an optimal angiographic result is achieved through "plain old balloon angioplasty" (POBA), with less than 30% residual stenosis, no dissection or residual thrombosis, and TIMI 3 flow, stenting may not be necessary. In such cases, waiting for 5–10 minutes to confirm a stable angiographic outcome is reasonable. However, if significant early elastic recoil, dissection, or residual thrombosis is observed, stenting the culprit lesion is advisable.

POBA is an acceptable alternative in scenarios where stent placement is challenging, such as in patients with excessive proximal tortuosity or calcification that prevents stent passage. Additionally, POBA with an acceptable angiographic result is useful for patients with very small-diameter infarct-related arteries or those with contraindications to long-term antiplatelet therapy, such as active bleeding.

BOX 13.3 REQUISITE CONDITIONS FOR PRIMARY PCI WITH NO SURGERY ON SITE

1. Experienced operators who regularly perform elective and primary PCI at tertiary centers
2. Nursing and technical staff experienced in handling acutely ill patients
3. Catheterization laboratories well equipped with resuscitative equipment and LVADs
4. Staff available 24/7/365
5. Protocols for emergent transfer to surgical centers (high-grade LM, unstable three-vessel disease)
6. Protocols addressing in whom to delay PCI (TIMI 3 flow with <70% residual stenosis, etc.) [1]

Tips and Tricks

****Where is the IRA?** During the diagnostic angiogram of a STEMI patient, it is essential to thoroughly visualize all coronary arteries and their branches. This is particularly critical when the culprit artery is occluded at its ostium, leaving no visible stump for easy identification. Prolonged imaging may reveal late retrograde filling of collateralized vessels, aiding in the identification of the IRA (Figures 13.2 and 13.3). Additional diagnostic clues, such as wall motion abnormalities, ECG findings, and any known prior coronary history, should be prioritized to pinpoint the likely culprit artery and confirm the IRA.

In a case report of a patient presenting with a classic inferior wall myocardial infarction (MI) and ST-segment elevation in leads II, III, and aVF, an emergency angiogram revealed a moderate lesion in the left anterior descending(LAD) artery. However, the right coronary artery (RCA) was not visualized, even with an aortogram. Given the typical symptoms and ECG findings, extensive efforts were made to locate the RCA. It was eventually identified in an anomalous location, originating from the left sinus of Valsalva, anterior and cephalad to the left main (LM) ostium. To access this anomalous RCA, a Judkins Left (JL)-4 guide was manipulated to create an additional upward angulation. Alternatively, other guides such as JL-5, Amplatz Left (AL), or a 6-Fr extra-backup (XB) guide can be utilized for this purpose (Figure 13.1). In another case encountered by one of the authors, a patient presented with severe chest pain. Angiography showed patent LAD, left circumflex artery (LCX), and RCA, leaving uncertainty about the IRA. Minor ST-segment elevation in leads I and aVL suggested the diagonal branch as the possible culprit. Using the left anterior oblique (LAO) cranial view, a wire was advanced to probe the suspected origin of a large diagonal branch. The wire successfully entered the branch, and PCI was performed successfully. In yet another case report, a patient with ST-segment elevation across all precordial leads (V1–V6) underwent coronary angiography, which initially showed only a minor LAD lesion. Upon switching to a larger guide catheter, an ostial dissection of the left main coronary artery (LMCA) was clearly visualized. This critical finding had been missed earlier due to the use of a smaller guide catheter that bypassed the LM ostial dissection. These cases emphasize the importance of careful catheter selection and imaging techniques in identifying and managing complex coronary lesions. [3].

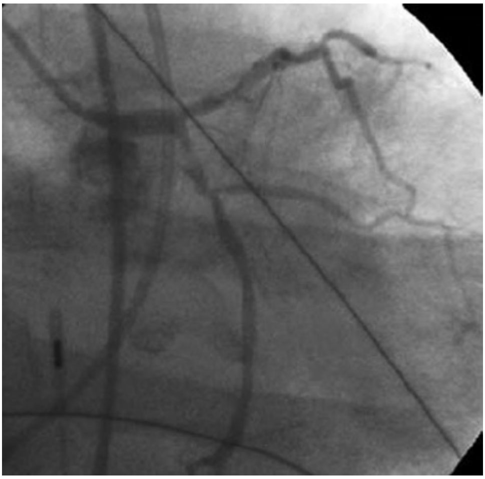


Figure 13.2 The LCX is completely visualized, but the flow is slower than the flow in the normal branch (TIMI 2 flow).

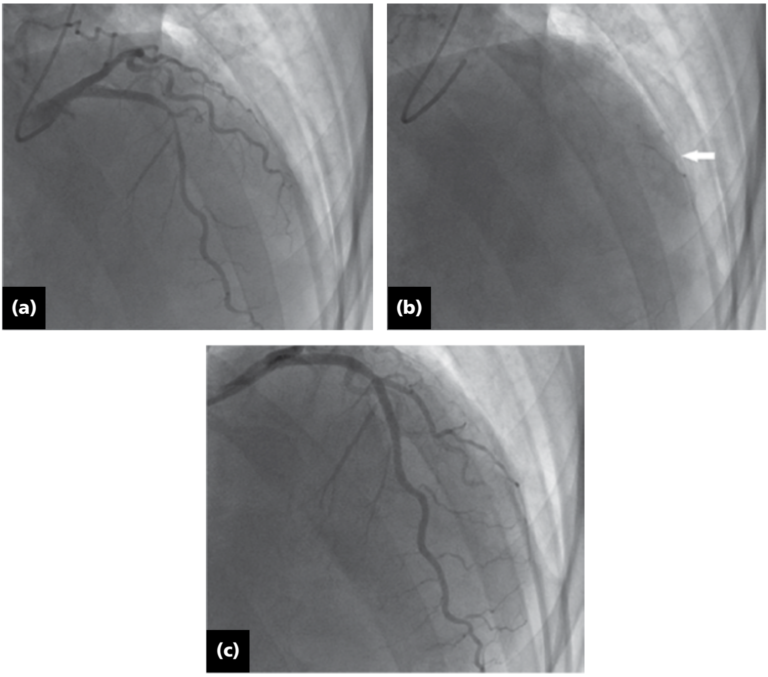
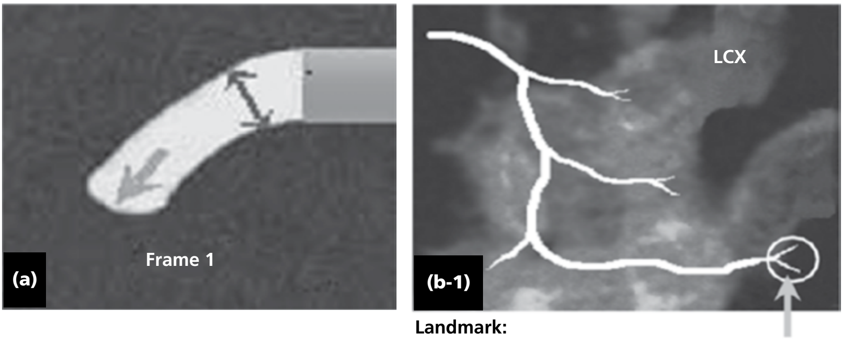


Figure 13.3 (a) Where is the IRA? The culprit for the patient's lateral ST-segment elevations is unclear. (b) Delayed angiography with extensive cine time revealed a late-filling distal diagonal vessel (arrow). (c) Final angiogram after stenting.

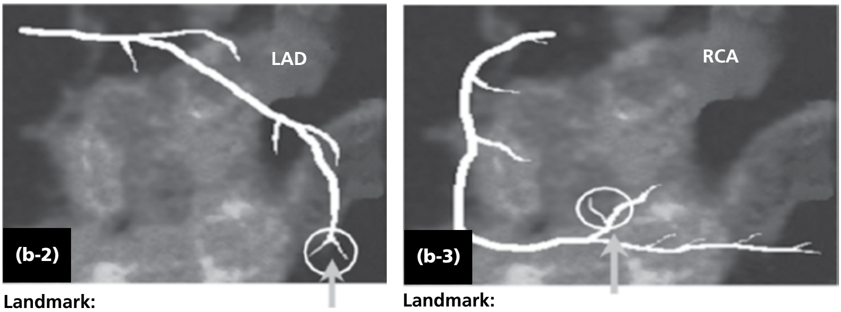
Avoiding vasovagal reaction Rapid restoration of coronary flow, particularly to the IRA supplying the inferior territory of the LV, can result in transient hypotension and bradycardia. While these are typically benign events, proactive management is essential. Patients with inferior STEMI should be aggressively hydrated before PCI, and the use of nitrates and β-blockers should be avoided. If hypotension and bradycardia occur, an intravenous (IV) atropine bolus (0.5–1.0 mg) and rapid infusion of colloid solution are recommended. Alternatively, intracoronary atropine (0.1–0.2 mg) may be administered for a faster onset of action while minimizing the risk of tachycardia. A venous sheath placed in the femoral vein prior to intervention can facilitate rapid fluid administration and allow for temporary pacemaker insertion, if necessary, although this need not be routine. Conscious patients may also be instructed to perform "cough cardiopulmonary resuscitation" to counteract brief episodes of hypotension and bradyarrhythmia. If there is a high likelihood of significant bradyarrhythmia, a temporary pacing wire can be positioned in the right atrium, ready for advancement into the right ventricle if needed. In emergencies, a 0.014-inch coronary guidewire can serve as a temporary pacing wire. For patients who develop ventricular fibrillation (VF) or ventricular tachycardia (VT) before arrival at the catheterization laboratory, defibrillation patches should be pre-applied to the chest and back to prepare for potential arrhythmia during reperfusion with a wire or balloon. These precautions help ensure rapid response to life-threatening complications during PCI.

Evaluation of the PCI Results

The primary goal of PCI in STEMI is to achieve a successful dilation of the culprit lesion, restore normal epicardial blood flow, and ensure adequate microvascular reperfusion of the infarcted myocardium. Beyond the categorical assessment of TIMI epicardial flow, a more precise



Landmark:
Last branch off most distal OM



Landmark:
Bifurcation of LAD at apex

Landmark:
First branch off posterolateral

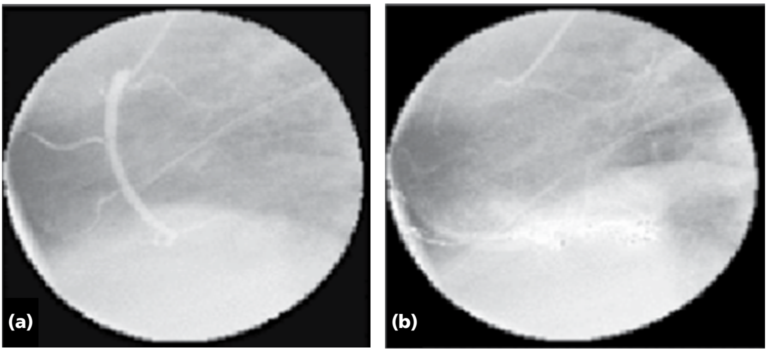
Figure 13.4 The corrected TIMI frame count. (a) The first frame is defined as the frame in which injected contrast touches the two borders but does not fully opacify it. The end frame is defined as the first frame in which contrast appears in the distal bed of the reference vessel. The distal landmark of the left circumflex artery (LCX) and obtuse marginal (OM) (b-1), the left anterior descending artery (LAD) (b-2), and the right coronary artery (b-3).

evaluation can be achieved using the corrected TIMI frame count (CTFC), which measures the number of angiographic frames required for dye to traverse a coronary artery (Figure 13.4) [4]. CTFC accounts for differences in coronary vessel size and length, reduces interobserver variability, and is an independent predictor of in-hospital mortality in STEMI patients. It also stratifies patients with TIMI 3 flow into low- and high-risk groups. However, restoration of flow in the IRA does not always guarantee tissue-level perfusion. To address this, the TIMI myocardial perfusion grading (TMPG) system was developed and validated. TMPG provides a simple bedside indicator of microvascular reperfusion and early resolution of ST-segment elevation, offering additional risk stratification for patients with successful epicardial reperfusion (Figure 13.5). These tools enhance the evaluation of both epicardial and microvascular outcomes following PCI.

COMPLEX PRIMARY PCI

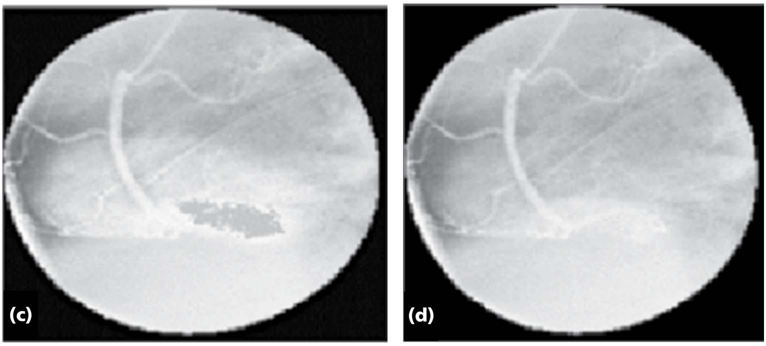
Unprotected LM as IRA

Most patients with sudden thrombotic occlusion of an unprotected LMCA die before reaching the cardiac catheterization laboratory (CCL). Those who survive hospital admission typically have intermittent LM occlusion, a dominant patent RCA, or an anomalous origin of the LCX,



TMP Grade 0
No or minimal
blush

TMP Grade 1
Stain present
Blush persists
on next injection



TMP Grade 2
Dye strongly
persistent at end
of washout
Gone by next injection

TMP Grade 3
Normal ground-glass
appearance of blush
Dye mildly persistent
at end of washout

Figure 13.5 The TIMI myocardial perfusion (TMP) grading system. (a) TMP grade 0: there is no dye entering the myocardium, and there is minimal or no blush apparent in the distribution of the culprit artery. (b) TMP grade 1 means the appearance of blush in the distribution of the culprit artery, which persists on the next injection approximately 30 s later. (c) TMP grade 2: there is a ground-glass appearance ("blush") or opacification of the myocardium that is strongly persistent after three cardiac cycles of the washout phase and either does not or only minimally diminish in intensity during washout. (d) TMP grade 3: there is a ground-glass appearance ("blush") or opacification of the myocardium in the distribution of the culprit artery that clears normally and is either gone or only mildly/moderately persistent at the end of the washout phase, similar to an uninvolved artery.

which improves their chances of survival (Figure 13.6). Patients with acute LM occlusion almost always present in profound cardiogenic shock, necessitating immediate initiation of percutaneous LV assist device (LVAD) support, vasopressors, inotropes, and mechanical ventilation prior to PCI. It is critical to differentiate between cases where the unprotected LM is the IRA and those where significant LM stenosis exists, but another coronary artery serves as the IRA. In cases where the unprotected LM is the IRA, only the culprit lesion should be treated during the index procedure if the patient is stable and free of ischemia following primary PCI. Conversely, in cases of significant LM stenosis with another artery as the IRA, revascularization of the unprotected LM should be deferred until the patient has recovered from the subacute

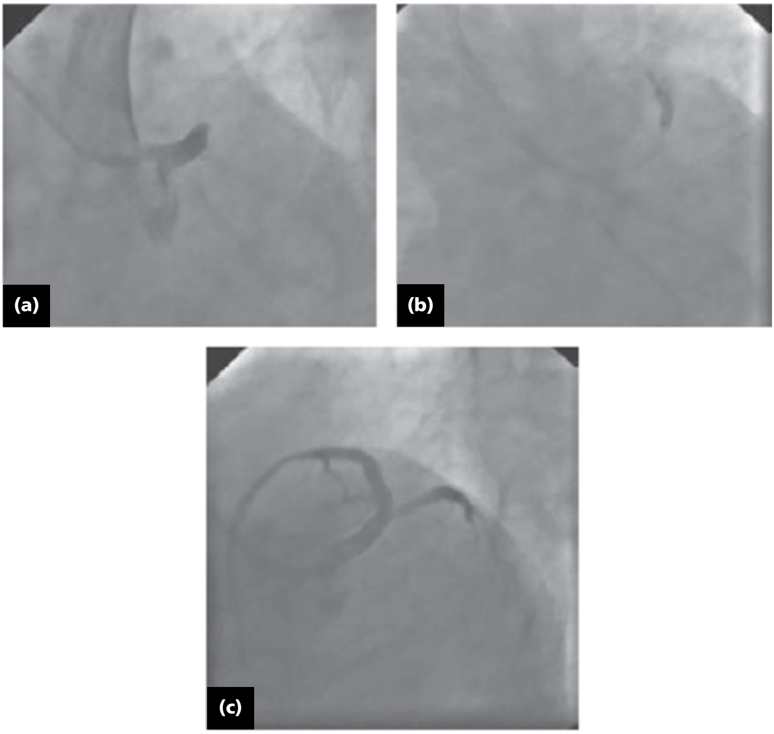


Figure 13.6 STEMI due to acute LM occlusion in a patient with small anomalous LCX arising from proximal dominant RCA. (a) Stump of the LM. (b) Following pre-dilatation, stenting with wire protection of large D1 was performed. (c) Final angiogram revealed widely patent LAD with some thrombus–plaque shift in D1 and TIMI 3 flow in both branches.

phase of STEMI. If ongoing ischemia persists due to significant LM stenosis despite successful PCI of the IRA and adequate hemodynamic support with a percutaneous LVAD, immediate PCI of the unprotected LM or coronary artery bypass grafting (CABG) should be strongly considered. Rapid decision-making and appropriate intervention are essential to improve outcomes in this high-risk population.

Tips and Tricks

****Thrombectomy in the LM** If a large thrombus is visualized in the LMCA, thrombus aspiration is essential to prevent downstream embolization. This can be achieved by using the guide itself as an aspiration device. To do this, a 20-mL Luer-lock syringe is connected to the proximal end of the guide, and strong suction is applied. Alternatively, a large-bore aspiration catheter (preferably 7 Fr) can be employed. Extreme caution must be exercised during this procedure to avoid retrograde emboli, which could potentially cause a stroke. Best is to use current dedicated thrombectomy catheters that are safer and effective.

PCI After Thrombolysis

When primary PCI is delayed or unavailable, many STEMI patients are treated with thrombolytic therapy (TT). Urgent PCI is recommended 3–4 hours after TT, and in cases of thrombolytic failure, immediate angiography and mechanical recanalization of the IRA remain the preferred treatment. Since clinical signs and ECG indicators of reperfusion are often imprecise, the American College of Cardiology/American Heart Association (ACC/AHA) guidelines recommend urgent angiography for patients receiving TT who experience ongoing chest pain, hemodynamic instability, or persistent ST elevation 90 minutes after TT, even if asymptomatic and within 12 hours of symptom onset. It is important to note that patients requiring rescue PCI due to failed thrombolysis are at higher risk for reocclusion. This increased risk may stem from factors such as resistance to pharmacologic reperfusion, large thrombus burden, or platelet-rich thrombi, all of which are less favorable for mechanical intervention. Rescue PCI should be performed on high-risk lesions (>75% stenosis) with TIMI flow ≤2 to optimize outcomes.

PCI in Right Ventricular Infarction

The clinical manifestations of right ventricular infarction (RVI) include signs of acute right ventricular (RV) failure, such as hypotension, jugular vein distension, a right-sided fourth heart sound, and occasionally a Kussmaul sign. Although rare, isolated RVI may occur under specific circumstances, such as occlusion of a non-dominant or co-dominant RCA proximal to an acute marginal branch or occlusion of the acute marginal branch itself. Isolated RVI can also result from acute occlusion of an RV branch following PCI. The coexistence of RVI with severe LV hypertrophy may exacerbate hemodynamic manifestations through two mechanisms. First, LV diastolic dysfunction can elevate pulmonary capillary wedge pressure, increasing the likelihood of RV failure. Second, the reduced LV preload due to RVI may have more severe consequences in the presence of LV diastolic dysfunction. Additionally, RV myocardial abnormalities associated with hypertrophic or hypertensive cardiomyopathy may further contribute to RV failure in these patients (Video 13.1) [5].

Video 13.1 Coronary angiogram with delayed washout of contrast in the vein is suggestive of right ventricular (RV) infarction causing pulmonary hypertension and RV failure.

PCI of Saphenous Vein Graft

STEMI in patients with a prior history of CABG is typically associated with saphenous vein graft (SVG) occlusion rather than mammary artery occlusion. These events generally affect smaller myocardial territories and present milder symptoms. Due to the large caliber of SVGs and their high thrombotic burden, there is a significant risk of distal embolization and the “slow” or “no-reflow” phenomenon during intervention [6].

When feasible, PCI of the native coronary artery supplied by the graft should be attempted first, provided there is a realistic likelihood of success. If this is not achievable, PCI of the SVG should be performed. To minimize distal embolization and improve angiographic and clinical outcomes, a distal protection device should be used when the anatomy and site of the culprit lesion allow (Figure 13.7). In cases of significant thrombotic burden, combining distal protection with thrombus aspiration is recommended to further reduce complications and enhance procedural success.

Tips and Tricks

Crossing the lesion when the RCA is the IRA Typically, the IRA is occluded by a soft and fresh thrombus, which can be easily crossed with a steerable floppy wire. There are two primary types of acute occlusions:

1. Soft and Fresh Thrombus on a Vulnerable Plaque: This type involves a soft, fresh thrombus superimposed on a vulnerable atherosclerotic plaque. Such occlusions can be readily crossed with a steerable floppy wire.
2. Occlusion Following Plaque Rupture: In this scenario, the IRA is occluded after the rupture of a large atherosclerotic plaque. When the IRA is the RCA, the plaque often forms along the inner border of a coronary curve, suggesting that the remaining lumen is likely located at the outer curve (Figures 13.8 and 13.9). Conversely, if the IRA is the LAD artery, the plaque tends to form in the myocardial site, indicating that the remaining lumen should be in the pericardial site.

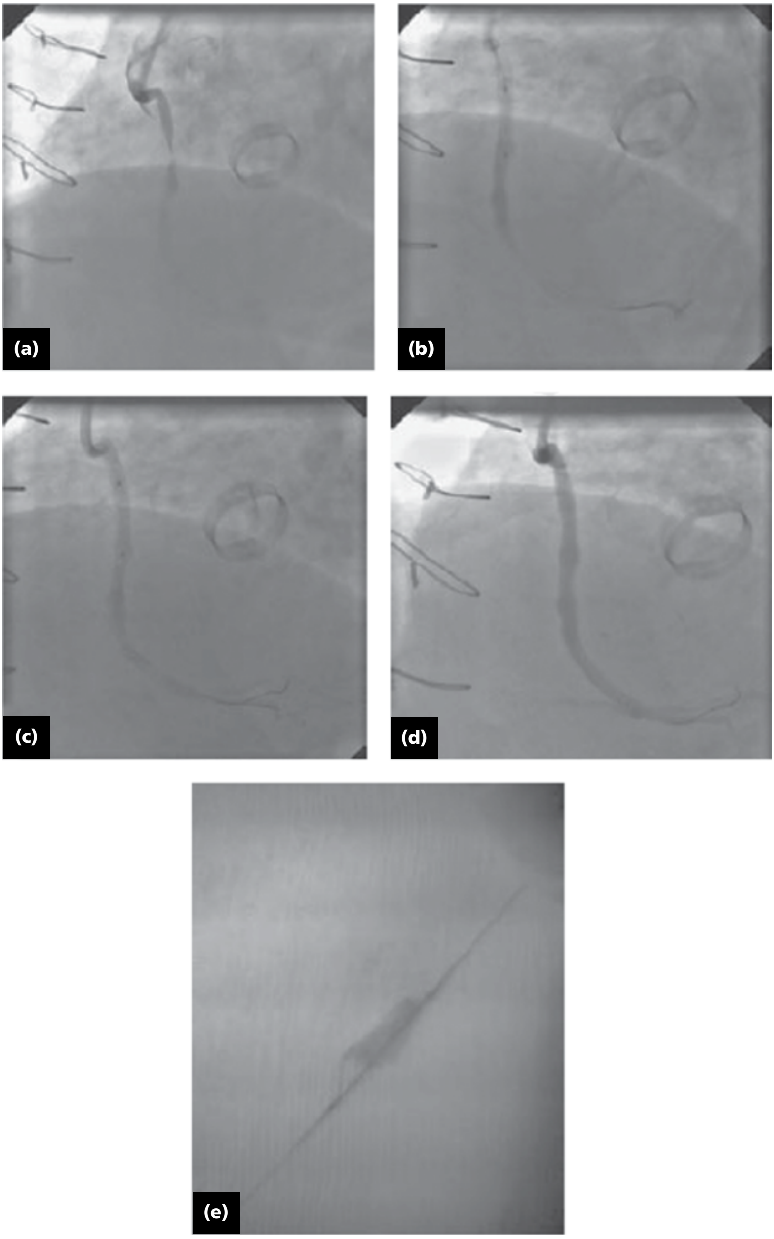


Figure 13.7 Acute occlusion of SVG to distal RCA with evolving inferior STEMI. (a) Thrombotic occlusion of the graft with TIMI 1 flow. (b) Balloon pre-dilatation using an undersized balloon with distal protection (FilterWire) in place. (c) Stenting of the culprit lesion under protection of FilterWire. (d) Good angiographic result after removal of FilterWire. (e) Captured thrombotic debris in the basket of the FilterWire.

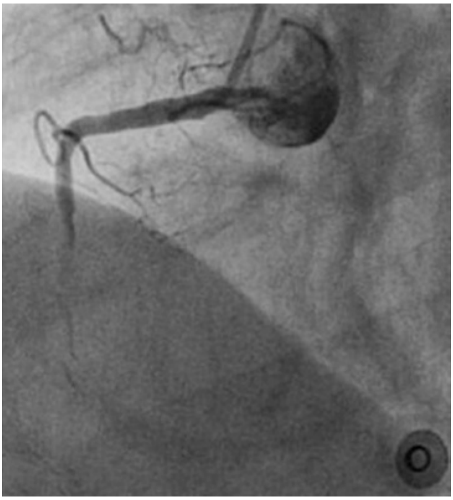


Figure 13.8 In this acute occlusion from STEMI, the remaining lumen is not visualized.

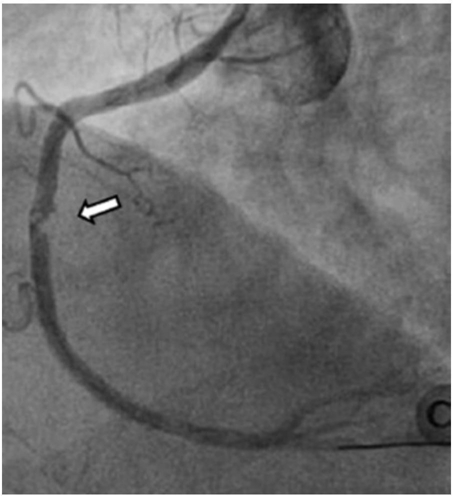


Figure 13.9 In a curved segment of an artery, the plaque (arrow) formed in the inner curve where the shear stress was lowest.

****Where to point the tip of the wire when crossing the lesion** When navigating a wire through the RCA, the wire tip should be directed toward the outer border of the RCA in the LAO view. For the LAD, the wire tip should be oriented toward the pericardium and away from the myocardium. To determine the location of the myocardium, the anterior-posterior cranial view can be used: the septals are on the right side of the patient, and the diagonals are on the left. The right side corresponds to the myocardial side, while the middle represents the roof of the LAD, and the roof and left side together form the pericardial side. Typically, plaques form on the myocardial side of the LAD and LCX, so the wire should be directed toward the pericardial side of these arteries. If the wire inadvertently passes under a ruptured plaque and a balloon follows, advancing the balloon under the intima can lead to dissection of the IRA and result in distal no-reflow. Inflating the balloon in this position would exacerbate the dissection. Subsequent stenting of the IRA at the lesion site could collapse the IRA distal to the stent, necessitating further stenting in the subintimal plane unless the distal true lumen is successfully re-entered and stented at the re-entry site.

****What to do if the wire cannot cross the lesion** In cases of tortuosity, where improved wire pushability is needed, a small balloon can be positioned near the distal tip of the wire to enhance its stability. Alternatively, an exchange microcatheter can be utilized. While these strategies may prolong the door-to-balloon time and increase procedural costs, they offer significant benefits. An over-the-wire (OTW) balloon or microcatheter not only provides enhanced support to the wire but also allows for verification that the wire is in the true lumen upon crossing the stenosis, which can be confirmed by a small intraluminal injection. Generally, stiffer and hydrophilic wires are not necessary for this purpose.

****How to prevent vasovagal reaction** Once the lesion has been successfully crossed, the lesion can be "dottered" by gently moving the uninflated balloon back and forth. This technique allows stagnant (and potentially acidic) blood from proximity to the occlusion to seep slowly into the distal vasculature rather than flooding it suddenly. This maneuver may reduce the risk of reperfusion injury and arrhythmias, particularly when the IRA is a large RCA. Additionally, this approach can help prevent thrombus embolization that may occur due to a sudden surge of antegrade flow.

****How to verify that the wire is in the true lumen** After "dottering" the balloon across the lesion, the operator can inject a small amount of contrast to confirm that the wire is positioned in the true lumen rather than in a side branch. If the wire's position remains uncertain, a small OTW balloon can be advanced. The wire is then removed, and contrast can be injected through the central lumen of the OTW balloon to verify true lumen placement. This maneuver also aids in assessing the artery's size, facilitating the selection of an appropriately sized balloon or stent for subsequent intervention.

Primary PCI for Lesions with Thrombi

In situations of small or moderate thrombotic burden, conventional PCI should be performed. The thrombotic burden is often large in patients with prolonged symptom duration or if the IRA is a large-diameter or ecstatic vessel such as an RCA or an SVG (Figure 13.10). In such cases, it is reasonable to remove the thrombus before stenting to reduce the likelihood of distal embolization in the IRA branches or microcirculation resulting in the "slow" or "no reflow" phenomenon.

Tips and Tricks

****Prevention of complications caused by an aspiration device** When using aspiration catheters, passes should be made along the entire length of the thrombus until no angiographic evidence of thrombus remains, as confirmed by a repeat diagnostic angiogram. If the thrombus is large, thrombotic material may clog the aspiration holes, halting the process. In such cases, after a few passes, the catheter should be removed, thoroughly flushed, and then re-advanced for additional passes. During the advancement and withdrawal of aspiration catheters, careful attention must be paid to the movement of the wire tip. If the wire tip remains stationary while the catheter is advanced, it may indicate that the catheter is bending the wire, creating a sticking point that could lead to arterial dissection or perforation. Once the aspiration catheter is removed, the guide should be immediately and generously aspirated. This is crucial because the aspiration catheter may drag the tail of a long thread thrombus, which could become dislodged and embolize into the guide, potentially causing complications.

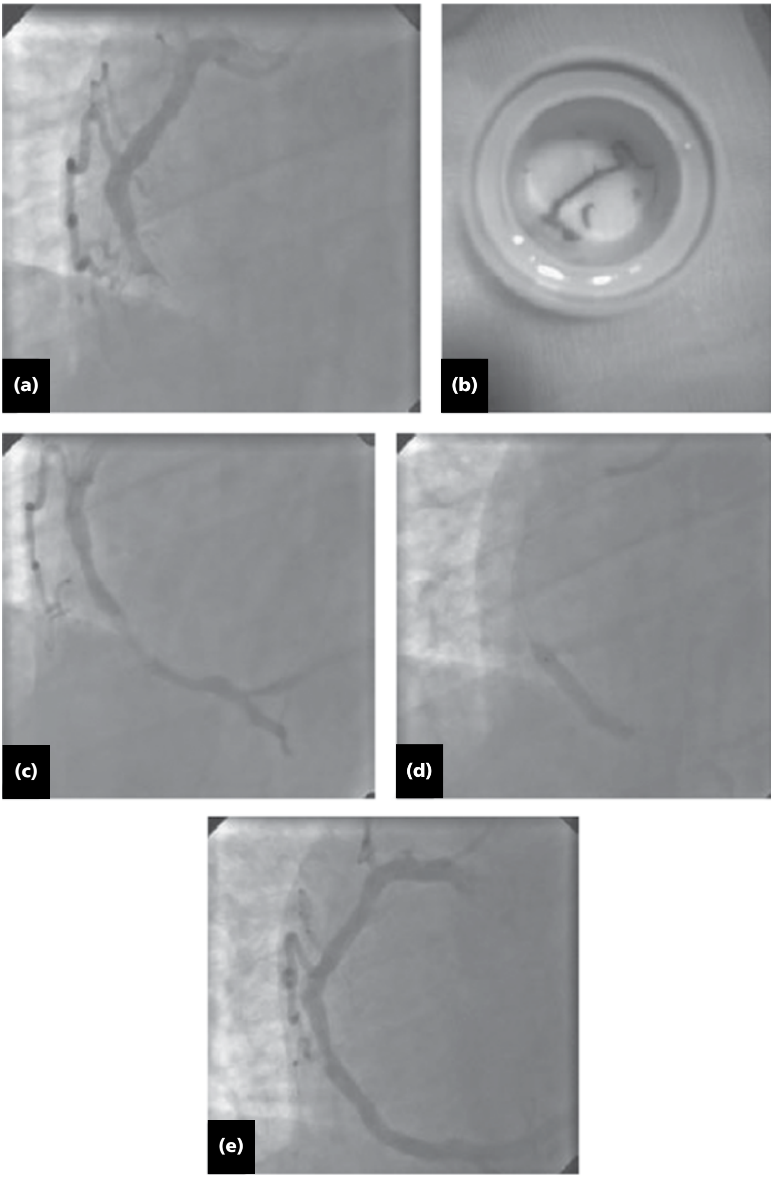


Figure 13.10 Catheter aspiration of thrombus in a patient with evolving STEMI in the territory of the dominant RCA. (a) Thrombotic occlusion of the mid-RCA. (b) Aspirated thrombus obtained after the first passage of the thrombectomy catheter, and no significant aspiration in subsequent passages. (c) Angiographic finding after aspiration. (d) Direct stenting of the culprit lesion. (e) Excellent final angiographic result with TIMI 3 epicardial flow, TMP 3, and significant early ST-segment resolution.

****Correct way to manipulate an aspiration catheter** Correct use of an aspiration catheter involves flushing the aspiration lumen fully and then advancing it proximally to the lesion with the port locked. Once proximal to the lesion, the aspiration lumen should be exposed to negative suction, and return of blood should be verified before advancing across the lesion. As long as good flow is maintained, several passes may be made before the device is removed, which should be done under continuous suction.

*****Avoiding antegrade embolization** Embolization to one or more branches of the IRA distal to the culprit lesion can occur due to strong contrast injection or as a consequence of thrombus dissolution by balloon inflation or stenting. This is why manipulation of hardware in the IRA must be gentle and minimal to avoid dislodgement of thrombus. The use of manual aspiration thrombectomy, which is easier to use and cheaper, is effective in reducing slow-flow phenomenon and increases the chance of normal flow at the end of the procedure. If embolization in a significant distal branch occurs, another wire should be placed in the embolized branch. The lesion can then be carefully "dottered" by moving a deflated balloon back and forth. If anterograde flow is established and a significant lesion is visualized, additional PCI may be performed if the branch supplies an important part of the myocardium (Figure 13.11).

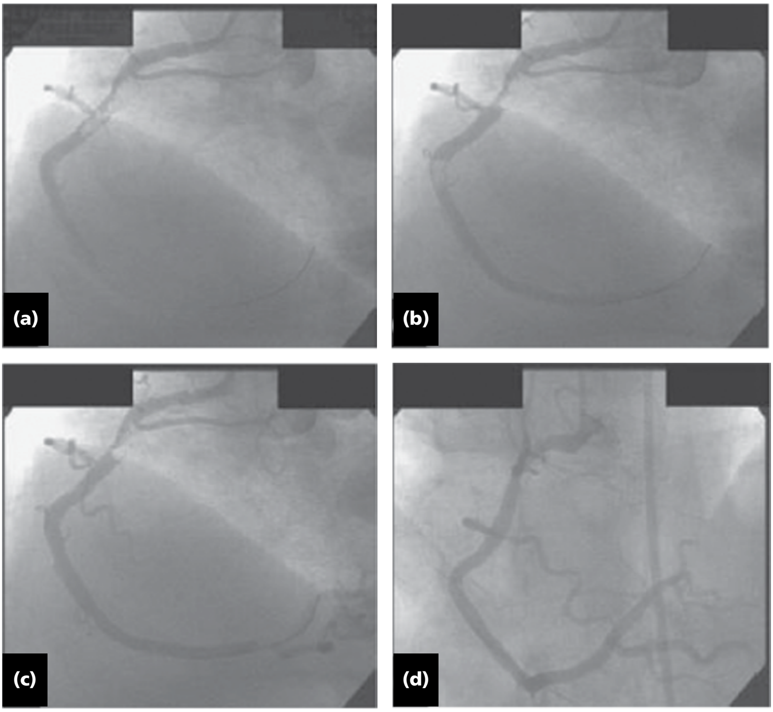


Figure 13.11 Distal embolization of large thrombus in the proximal dominant RCA in a patient with STEMI and cardiogenic shock. Following smooth passage of the wire, angiography of the RCA was performed. (a) At the beginning of coronary injection, a large proximal thrombus was identified. (b,c) During the contrast injection, a large part of the thrombus detached and traveled through the mid-portion of the RCA and stopped at the crux. (d) Following direct stenting of the culprit lesion and catheter aspiration of the distal thrombus, a good angiographic result was obtained.

*****Avoiding retrograde embolization** During PCI or thrombectomy at the proximal segment of the LAD and LCX, fragments of large thrombi may be squeezed back and occlude the ostium of the adjacent vessel. Fragments of the thrombus can even adhere to balloons or the aspiration catheter, which, when withdrawn or retracted into the guide, may lead to embolization and occlusion of the non-IRA branches. Occlusion of a large non-infarcted vessel may have dramatic consequences, including immediate cardiac arrest and profound cardiogenic shock. Embolization may be minimized by first opening the Y connector before injection of contrast agent and allowing backflow to remove any free thrombotic material. If an ostial LAD or LCX culprit lesion is treated, it is reasonable to protect the adjacent vessel with a distal protection device or an additional wire to allow for immediate intervention if required (Figure 13.12).

DEDICATED EQUIPMENT

E

The Thrombectomy Catheters

It is not always possible to achieve optimal thrombectomy, particularly in cases involving a large thrombus burden. The flow rates achievable to extract thrombus using such simple thrombectomy catheters may be limited by the radius of the catheter lumen. Furthermore, in contrast to thrombus burden related to STEMI, where the thrombus is mainly fresh and may be relatively easier to extract, the thrombus burden in SVG cases is complex, bulky, atheromatous, well-organized, and highly viscous. The Heartrail™ "five-in-six" catheter (Heartrail, Terumo, Japan) has an internal luminal diameter of 0.059 inch, while the Export Advance™ catheter (Medtronic Inc., Santa Rosa, California, USA) has an internal luminal diameter of 0.040 inch, and the Pronto® LP catheter (Vascular Solutions, Minneapolis, MN, USA) has an internal luminal diameter of 0.056 inch. According to Poiseuille's law, flow achieved through a Heartrail catheter would be 3.2-fold greater than an Export catheter and 1.2-fold greater than a Pronto LP catheter, which may in part explain the optimal thrombectomy results achieved in cases following use of the Heartrail catheter. Use of the Heartrail catheter in these situations has the advantage in that many thrombectomy devices used in cases of large thrombus burden or following suboptimal results with simple thrombectomy devices, such as the X-Sizer™ (EndiCOR Medical, Inc., San Clemente, California, USA) or ThromCat® (Spectranetics International; Leusden, the Netherlands) or hydrodynamic thrombectomy systems such as the AngioJet™ (Boston Scientific Corporation, Marlborough, MA, USA), are more complex to use and have had mixed outcomes in larger studies. The usual thrombectomy catheter requires a 7-Fr system, while the Heartrail system requires only a 6-Fr guide [7].

Advantages and limitations An aspiration thrombectomy device can bring a large amount of thrombus into the LMCA, a potentially life-threatening complication. This should be recognized as a potential complication in the left coronary system with a large thrombus burden. Important questions remain as to whether utilizing a larger-diameter guide (i.e. 7 Fr) can reduce the risk of thrombus shearing off the tip of a thrombectomy catheter as it is withdrawn. Another important issue is the optimal technique for aspiration; manufacturers' instructions recommend stopping negative suction before removing the catheter from the target vessel, but many interventionalists remove these devices on negative suction to avoid losing thrombus when removing the device. In addition, other devices, such as balloons, have the potential to bring thrombus back into the LM, and the comparative risk with thrombectomy devices is unknown. Other potential complications of aspiration thrombectomy include stroke, air embolization, distal embolization of thrombus, and vessel dissection and perforation [8].

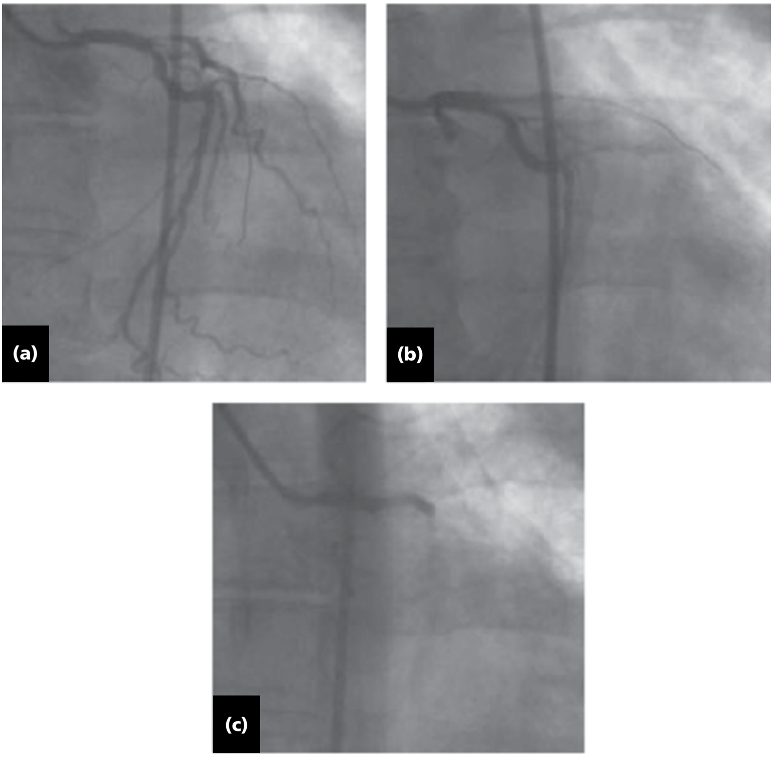


Figure 13.12 Retrograde thrombus embolization. (a) During PCI of the proximal segment of the LAD, a well-organized large thrombus was seen to be benign with balloon angioplasty. (b) The thrombus was then squeezed back during stenting. (c) This resulted in acute occlusion of the LCX, causing cardiac arrest.

Large Coronary Thrombus

Coronary angiography revealed that the culprit lesion was a subtotal LMCA occlusion, with TIMI trial flow grade 1 in the LAD associated with a filling defect compatible with an aggressive thrombotic process (TIMI thrombus scale classification 3) (Figure 13.13a). The Impella CP® device (Abiomed, Inc., Danvers, MA, USA) was implanted for LV support via the left femoral artery for cardiogenic shock. Aspiration thrombectomy was unsuccessful. The AngioJet (Boston Scientific Corporation, Marlborough, MA, USA) was not used due to proximity to the aorta, risk of peripheral embolism including stroke, and aortic dissection. Finally, thrombectomy was attempted with a 4 × 20 mm Solitaire™ FR revascularization device (ev3-Covidien, Irvine, CA, USA) in the LMCA and LAD but was unsuccessful. A second attempt was made with a 6 × 30 mm Solitaire FR device (Figure 13.13b), resulting in TIMI flow grade 3 and complete thrombus disappearance.

STEMI Due to Emboli

Angiographic appearances with features suggestive of thromboembolic infarction include abrupt vessel cutoff, no obvious atherosclerotic plaque in the vicinity, and paucity of collaterals (Figure 13.14). The patients have an obvious cause for emboli (i.e. either prosthetic valves or AF) [9].

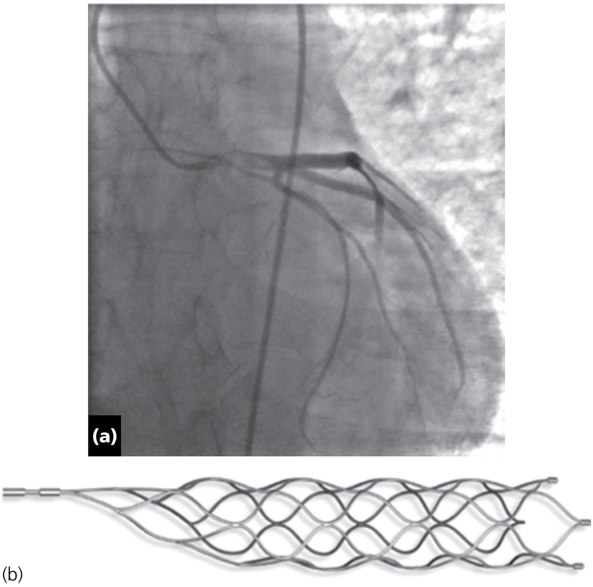


Figure 13.13 (a) Coronary angiogram revealing a large radiolucent filling defect in the LMCA. (b) Solitaire FR revascularization device.

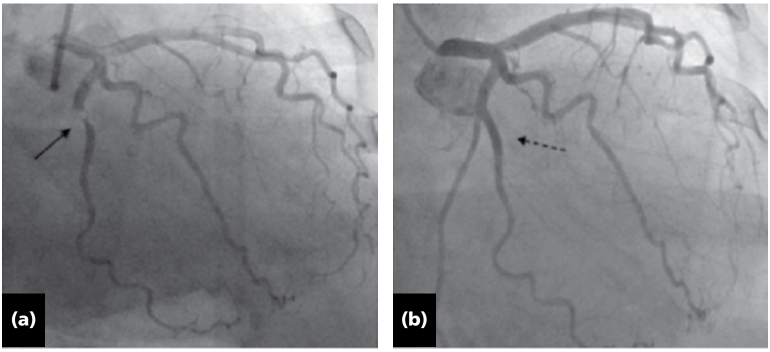


Figure 13.14 Embolus in the LCX causing AMI. (a) Occlusion of the LCX at the first bifurcation (arrow). (b) After multiple runs of aspiration, the underlying vessel appears angiographically normal, obviating the need for further intervention.

Tips and Tricks

"Slow" or "no reflow" after stenting Diminished epicardial blood flow in the presence of a widely patent IRA is known as the "slow" reflow (TIMI 2) or "no reflow" (TIMI 0 or 1) phenomenon. This condition is primarily due to compromised distal microvascular perfusion. The mechanisms underlying "slow–no reflow" are likely multifactorial, involving microvascular embolization of thrombus and plaque debris, subsequent platelet activation, release of potent vasoconstrictors, and microvascular spasm. If encountered, the flow may improve following the infusion of adenosine, nicorandil, calcium channel blockers, or nitroprusside.

If flow remains unestablished, it may indicate plugging of the microvascular bed ("no reflow"), necessitating distal delivery of arterial dilators such as adenosine, nitroprusside, or nicardipine. This can be achieved by advancing the aspiration device beyond the lesion under gentle flush to avoid picking up errant thrombus, allowing for more precise and targeted drug delivery.

As a last resort, if "no reflow" persists despite these interventions, blood may be aspirated and forcefully re-injected into the coronary artery using a 10- to 20-mL syringe to unplug the microvasculature. However, this technique carries significant risks, including distal air or thrombus embolization, and should be used with caution.

Persistent Thrombotic Burden

In a case of persistent thrombus after repeated balloon angioplasty, check the wire to be sure that it is inside the main lumen. If it is not due to the wire, then the best management would be to attempt thrombectomy using either the AngioJet or the X-Sizer device if the thrombus is large. Smaller distal thrombi can be aspirated by a Pronto or Export catheter.

Any residual thrombus could be lysed by intracoronary recombinant tissue plasminogen activator (r-tPA; 5-mg boluses down the LCA via the guide every 5 min). Up to 50 mg will usually suffice. If the vessel then looks clear of thrombus and distal coronary flow appears good, IV heparin over the next 24 h should be continued [activated clotting time (ACT >200 s)]. If residual thrombus appears to exist or distal coronary flow appears suboptimal, abciximab should be given (intracoronary bolus followed by a 12-h IV infusion) [10].

PCI FOR PATIENTS WITH CARDIOGENIC SHOCK

After angiography, a decision must be made to proceed immediately to intervention or consider initial insertion of an LVAD. Upfront placement (prior to intervention) should be considered in patients with extremely high-risk features (Box 13.4). These patients have high morbidity and mortality and sometimes worsening after initial vessel opening. Therefore, initial intervention of an LM occlusion should not be attempted until the support device has been initiated.

Although supporting evidence for the usefulness of these devices is mixed, percutaneous LVADs can provide essential backup cardiac output. Several support devices are available. Each device has its various strengths and weaknesses (Table 13.1), but all require assessment of the patient's femoral and iliac vessels first. Severe peripheral disease not amenable to a quick balloon angioplasty will preclude the use of most devices. If available, an Impella CP device (Abiomed, Inc., Danvers, MA, USA) may provide the most rapid, reliable cardiac output on average compared with an intra-aortic balloon pump (IABP), extracorporeal membrane oxygenation (ECMO), or TandemHeart® (CardiacAssist, Inc., Pittsburgh, PA, USA).

Impella

The Impella device, a non-pulsatile axial flow system inserted retrogradely across the aortic valve, is available in two FDA-approved configurations: the Impella 2.5, which provides up to 2.5 L/min of cardiac output via a 12-Fr sheath, and the Impella CP, capable of delivering up to 4 L/min via a 14-Fr sheath (Figure 13.15).

BOX 13.4 TRIGGERS FOR UPFRONT SUPPORT DEVICE

1. Left main occlusion (or equivalent)
2. Cardiogenic shock
3. Cardiac arrest
4. High-grade coronary disease with low ejection fraction (<35%) and elevated LVEDP

Table 13.1 **Comparison of Percutaneous Support Devices**

Device	Cardiac support (L/min)	Arterial cannula size	Advantages	Disadvantages
IABP	0.5–1.0	7–8 Fr	Quick placement	Minimal support Poor outcomes data
Impella	2.5–5.0	12 Fr (2.5) 14 Fr (4.0) 21 Fr (5.0)	Quick placement Low profile	Multiple contraindications Cost
TandemHeart	2.0–5.0	15–19 Fr	Ventricular septal defect Aortic insufficiency	Difficult placement Cost
ECMO	>3.0	15–17 Fr	High-output support	Needs perfusion team Will not unload LV

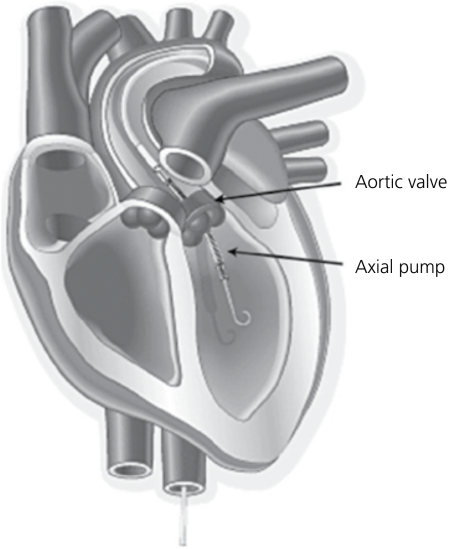


Figure 13.15 The Impella catheter.

Impella placement is contraindicated in patients with LV thrombus or a mechanical aortic valve and should be carefully reconsidered in cases involving ventricular septal defect, mitral regurgitation, or severe aortic stenosis. Additionally, it shares contraindications with IABP.

To minimize complications at the femoral access site, it is recommended to perform a "preclose" of the femoral arteriotomy using two criss-crossed Perclose sutures. This precaution reduces the risk of access-site complications, which can lead to poor outcomes or even mortality. Proper patient selection and meticulous technique are critical to ensuring safe and effective use of the device. The use of the Impella is discussed in detail in Chapter 17.

Extracorporeal Membrane Oxygenation

ECMO offers complete bypass and cardiopulmonary support by circulating venous blood through a pump/oxygenator. This device can provide concomitant therapeutic hypothermia. Because of its large-bore arterial access, the need for a perfusion team, and high cost, ECMO is typically reserved for STEMI cases with refractory shock, incessant VT/VF, and an inability to oxygenate. It can be used for pure oxygenation (veno-venous [V–V]), hemodynamic support (veno-arterial [V–A]), or hemodynamic support with added oxygenation (veno-arterio-venous [V–A–V]).

PCI FOR STEMI PATIENTS WITH CURRENT BLEEDING

In general, the principle is that PCI can be performed if the bleeding can be stopped by mechanical means (compressing or ligating the artery) and the patient can tolerate 4 h of anticoagulant without excessive further bleeding during PCI. The favorite anticoagulant is unfractionated heparin (UFH) because of its short half-life and because it can be reversed by protamine.

Patients with Bleeding Due to Leg Fracture

A patient had an acute myocardial infarction (AMI) when driving a car. The patient lost control of his car and hit an oncoming vehicle. The patient suffered a fracture in the leg with profuse bleeding. In the emergency room, the orthopedic surgeon placed splints and stabilized the extremities without doing surgery because of ongoing AMI. The patient underwent a femoral angiogram to check whether extravasation of contrast was due to an injury in the arterial system. As there was no arterial bleed in the extremities, the patient underwent plain balloon angioplasty (POBA) of the IRA under coverage of UFH and aspirin. After POBA of the IRA (RCA), the patient underwent leg surgery. At the present time, ongoing intracranial, lower intestinal, or esophageal variceal bleeding is the only contraindication for primary PCI.

Tips and Tricks

****How to know when the patient with bleeding will develop low blood pressure** The size of the common femoral vein (CFV) and its expansion with cough can be measured with ultrasound equipment or any echocardiography machine with a vascular probe. The location at which to point the probe is the strongest femoral pulsation. The ultrasound plane of the common femoral artery (CFA) and CFV is the coronal plane immediately proximal to the bifurcation of the superficial and deep femoral artery. In patients with normal fluid status, the size of the CFV is equal to that of the CFA (Figure 13.16a).

When a patient is dehydrated due to bleeding or blood loss, the size of the CFV is smaller than that of the CFA (Figure 13.16b). In a patient who came in with bleeding in the large bowel, after cauterization of the bleeding site, the ultrasound showed a normal size of the CFV. After that, the blood pressure did not decrease again. This test could help to predict the short-term stability or instability of the blood pressure [11].

AMI in Patients with Gastrointestinal Bleeding

A patient presented to the emergency room with chest pain and developed recurrent VF in the waiting area, requiring seven defibrillation shocks. The patient's family reported a history of vomiting blood three days prior to admission. An ECG revealed ST-segment elevation in leads V2–V6. The patient was promptly taken to the CCL, where balloon angioplasty was performed on the proximal LAD. During the procedure, heparin (5,000 IU) and aspirin (100 mg) were administered. Heparin was chosen because its anticoagulant effects can be reversed if further bleeding occurs. Although bivalirudin may reduce bleeding risk, it lacks an antidote for reversal. No stent was used, and therefore, a P2Y12 inhibitor was not administered. The technical goal of the procedure was achieved with TIMI grade 3 flow restoration in the IRA following PCI.

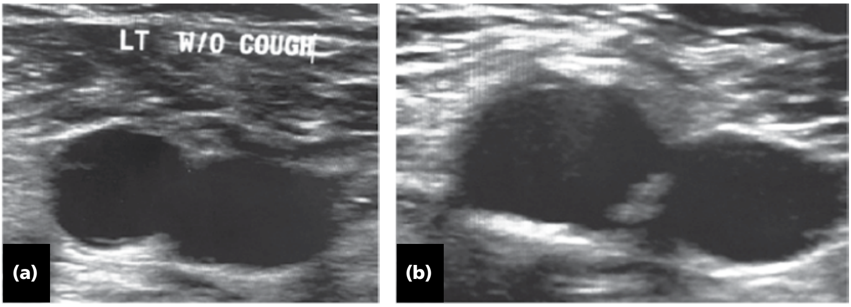


Figure 13.16 (a) The common femoral artery is recognized as a round structure on the left, and the common femoral vein on the right. Without a cough, they are of the same size. (b) In this image, the size of the common femoral vein is smaller than that of the common femoral artery. This patient had bleeding in the stomach due to an ulcer.

AMI in Patients after Recent Surgery

Less than four hours after undergoing a right nephrectomy for cancer, a patient developed ST-segment elevation in leads II, III, and aVF. The patient was promptly taken to the CCL, where balloon angioplasty was performed on the RCA using a standard dose of heparin to achieve an ACT of 250–300 seconds. No stent was placed, and no additional heparin was administered after the procedure.

Because heparin was used only for a short duration, minimal bleeding was observed at the surgical site, and there was no long-term impact on the surgical outcome. In cases where the surgery is clean and limited, PCI with a drug-eluting stent may be considered, as antiplatelet therapy following recent surgery typically does not result in significant long-term complications [12].

AMI in Patients with Concurrent Stroke

In cases where a patient experiences an ischemic stroke, they may be considered for short-term anticoagulant therapy (such as UFH or direct thrombin inhibitors [DTI]) alongside long-term oral antiplatelet drugs, provided there is agreement from the neurologist involved. Following this, the patient could undergo PCI and stenting. However, two primary concerns must be addressed:

1. Risk of Hemorrhagic Conversion: Anticoagulant therapy may increase the risk of hemorrhagic transformation of the ischemic stroke.
2. Risk of Cerebral Emboli: If the stroke was caused by emboli from a protruding plaque in the aortic arch, there is a risk of further cerebral emboli during the procedure.

The decision to proceed with PCI should be based on a strong indication for the procedure, and both the patient and their family must be fully informed about the potential benefits and risks. If the benefits outweigh the risks, PCI can be considered.

Alternatively, if the patient presents with both ischemic stroke and STEMI, simultaneous thrombolytic therapy could be an option. However, the dosages for intravenous tissue plasminogen activator (tPA) differ between stroke and STEMI. For ischemic stroke, the standard dose is typically 0.9 mg/kg, with a maximum of 90 mg, administered over 60 minutes. For STEMI, thrombolytic therapy is not commonly used in conjunction with tPA due to different treatment protocols, but if considered, it would involve specific dosing regimens not typically aligned with stroke treatment protocols. The decision to use thrombolytics in such scenarios requires careful consideration and consultation with specialists.

AMI in Patients with Recent Stroke

A patient developed a left-sided facial droop, and magnetic resonance imaging showed an acute right frontoparietal infarct and a right parietal subdural hematoma. His oral dual antiplatelet therapy was continued, and repeat neuroimaging studies confirmed that the hematoma was stable.

On hospital day 14, the patient developed acute inferior ST-segment elevation again, complicated by complete heart block and hypotension. The patient was taken to the CCL and successfully underwent PCI with bivalirudin [13].

STEMI in Patients with Atrial Fibrillation (AF) on Direct Oral Anticoagulants

Coumadin does not have any effect on platelet function, so patients with a therapeutic international normalized ratio (INR) can still have STEMI. During PCI, the patient can be given oral loading and a maintenance dose of an antiplatelet drug such as aspirin or clopidogrel as usual. If the patient has a therapeutic INR (2–3), no UFH is needed. If the INR is <2, the patient can be given UFH (as in the protocol for treatment of pulmonary embolism). Primary angioplasty for STEMI can safely be performed via a transradial artery approach in patients at high risk of bleeding.

ADVANCED AND EXOTIC TECHNIQUES

AMI Patients with LM Compressed by an Aortic Dissection

A patient presented to the emergency room with STEMI and underwent coronary angiography. The initial injection revealed a severe stenosis of the LM with persistent contrast in the LAD and LCX arteries, despite a normal pressure curve without ventricularization. This finding suggested extrinsic compression of the LMCA. The guide catheter was withdrawn to the left coronary sinus, where a stronger injection demonstrated an acute aortic dissection (AAD) with a false lumen compressing the LMCA. Re-engaging the left coronary ostium and performing a more forceful injection revealed complete resolution of the stenosis, showing a wide-open LM with intermittent diastolic collapse of the lumen – a classic sign of coronary artery compression. A diagnosis of AMI secondary to LM compression by Stanford type A AAD was made. Direct stenting of the LM was performed as a bridge to potential aortic surgery. Post-stenting supravalvular aortography confirmed the dissection, displaying a “swinging lumen” phenomenon, where lumen size varied with systolic and diastolic flow. In cases of severe amplitude, diastolic interruption of coronary flow can result in persistent contrast filling despite normal aortic pressure curves [14].

AMI Due to Spontaneous Coronary Artery Dissection

Spontaneous coronary artery dissection (SCAD) in young and pregnant women presents unique challenges for PCI. Luminal compression can be extensive due to varying sizes of intramural hematomas within the vessel wall, complicating the procedure. Repeated selective angiography may worsen the condition, as contrast injections can increase pressure in the false lumen, potentially exacerbating the dissection. During PCI, there is a significant risk of the guidewire inadvertently entering the false lumen, which can lead to extension of the dissection or vessel perforation. To confirm that the wire is in the true lumen, advancing it into side branches can serve as a reliable indicator. Given these complexities, PCI for SCAD requires meticulous technique and should be reserved for cases where conservative management is not feasible or when there is ongoing ischemia or hemodynamic instability [15].

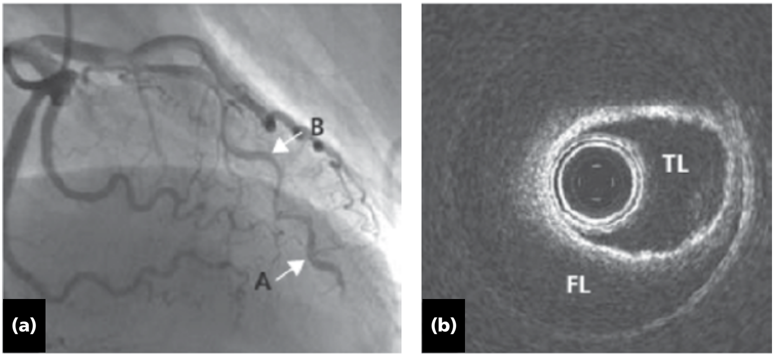


Figure 13.17 (a) Coronary angiography suggesting a spontaneous dissection in the mid-LAD (arrow A); its proximal extent is estimated to be at the location of the step-down in vessel caliber (arrow B). (b) OCT image revealing the presence of a dissection. The true lumen (TL) is compressed by a large intramural hematoma in the false lumen (FL). Reproduced with permission from [17] / National Library of Medicine / Public Domain.

Imaging strategy Coronary luminal imaging with intravascular ultrasound (IVUS) or optical coherence tomography (OCT) can play a critical role in guiding PCI, particularly in complex cases. These imaging modalities help resolve diagnostic uncertainties, such as identifying the extent of a false lumen when contrast fails to penetrate it, and provide precise visualization of anatomical landmarks. IVUS and OCT are instrumental in confirming accurate wire placement within the true lumen and in determining the appropriate stent diameter, length, and optimal deployment. Imaging may also influence procedural decisions, such as reconsidering the need for ballooning or stenting. Extensive stenting carries risks, including side-branch compromise, in-stent restenosis, and stent fracture [16] (Figure 13.17).

Primary PCI in STEMI After Resuscitated Cardiac Arrest

After successful cardiopulmonary resuscitation in patients with cardiac arrest, a 12-lead ECG may reveal STEMI, a condition observed in approximately 5–10% of STEMI cases. Urgent coronary angiography and primary PCI have been shown to be feasible, effective, and safe in these patients, with hospital survival rates reaching 77%. However, the primary determinant of survival is the extent of post-resuscitation brain injury. Patients who regain consciousness following the return of spontaneous circulation have survival rates comparable to STEMI patients without preceding cardiac arrest. Conversely, in patients who remain comatose upon arrival at the CCL, survival drops to just over 50%, with good neurological recovery achieved in less than 30% of cases [18].

AMI in Patients with a Large Coronary Aneurysm

A patient with a history of Kawasaki disease was diagnosed with STEMI, showing thrombotic occlusion of an aneurysm in the RCA. Thrombus removal was attempted with an aspiration catheter, but a large thrombus burden remained. The decision was made to perform intracoronary thrombolysis with a pulse infusion thrombolysis (PIT) catheter (Hand PIT) designed to allow intermittent thrombolytic agent delivery directly to the thrombus through side holes connected to a manual pump. After the PIT with a total 800 000 IU dose of tPA had been used, the thrombus was noted to have disappeared. An adjunctive simple balloon angioplasty was performed, and TIMI 3 was achieved. A coronary stent was not used to avoid malapposition and acute thrombotic occlusion. The patient was stable after the procedure during the inpatient hospital stay and had an uneventful recovery thereafter. This case suggests that PIT might be a useful strategy in cases of STEMI with massive thrombus in a giant coronary aneurysm [19].

AMI in Acute Simultaneous Proximal Occlusion of Two Major Coronary Arteries

In AMI, the acute simultaneous proximal occlusion of two major coronary arteries (ASOMC) is a rare event. When more than one occluded artery is present during AMI, usually only one occlusion is an acute event; the others are chronic occlusions.

The presence or absence of collaterals affects the symptoms and clinical outcomes of these patients. Patients without a history of angina can die from pump failure despite effective reperfusion therapy – the pump failure is then due to the absence of collaterals to the left coronary system from the RCA. In contrast, patients with a history of stable angina due to severe coronary artery disease and good collaterals from the RCA can fare relatively well. Concerning the latter, the incidence of normal postinfarction LV ejection fraction is higher than in those without significant collateral circulation [20].

PCI of a Reconstructed Prosthetic LM

In a case report, a patient with known Marfan syndrome and an extensive history of complicated aortic operations presented with chest pain and ST-segment elevation in the V leads. In the past, because of aortic aneurysm, the patient had had a Bentall procedure, which essentially involves the complete replacement and exclusion of the ascending aorta with a composite Dacron tube graft and implantation of an aortic valve prosthesis. The coronary arteries are then reimplanted onto the sides of the aortic tube graft. Because of aneurysmal change in the aortic graft, the patient underwent a second procedure including a redo replacement of the ascending aorta with a 28-mm tube graft, repair of the anterior and left posterolateral sinus of Valsalva, reimplantation of his RCA using the classic Bentall technique, and reimplantation of his LM coronary ostia utilizing a 10-mm Dacron graft (Cabrol graft) involving connection of the native coronary artery ostium to the aortic tube graft (Bentall) in a side-to-side manner by utilizing an interposed 8- to 10-mm diameter Dacron tube graft. During PCI for AMI, aortic root angiography demonstrated the usual position takeoff for the RCA and a high superolateral takeoff for the Cabrol graft. A standard (JR-4 diagnostic catheter managed to cannulate the RCA, which was angiographically unremarkable. Injections of the Cabrol graft confirmed a 90% severe hazy stenosis at the ostium of the LM at the anastomosis with the Cabrol graft. A JR-4 guide was used to engage the Cabrol graft. A 0.014-inch, 300-cm supportive wire was passed into the distal LAD. The LM was stented successfully [21].

MANAGEMENT OF NON-CULPRIT ARTERIES AND LESIONS

Tips and Tricks

Assessment of patency and flow in non-culprit arteries In patients with STEMI, the ventricular wall supplied by the non-culprit artery often undergoes compensatory hyperdynamic contraction to maintain adequate cardiac output. This increased mechanical stress may exacerbate injury at vulnerable segments, particularly at anatomical hinge points of the non-culprit arteries. When a severe lesion is suspected in the non-culprit artery, it is prudent to perform a repeat angiogram following successful revascularization of the culprit lesion. This allows reassessment of wall motion, perfusion dynamics, and lesion severity in the non-culprit vessel once the compensatory state has stabilized. In one such case, a follow-up angiogram performed three months after primary intervention demonstrated resolution of the previously suspected lesion at the hinge point, supporting the value of delayed reassessment (Figure 13.18a–d).

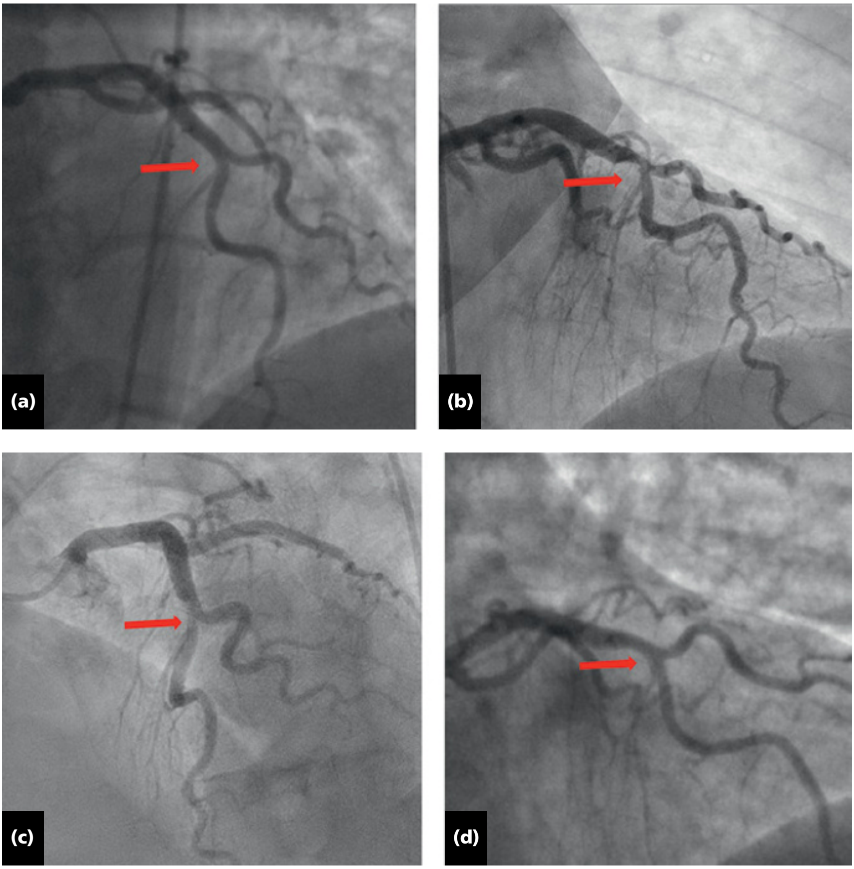


Figure 13.18 (a) This is the coronary angiogram of 6/2022 with patent mid-segment of the left anterior descending artery (LAD). (b) in 11/2024 patient had inferior wall myocardial infarction with acute occlusion of a dominant right coronary artery (RCA). The mid segment of the LAD showed moderate lesion before stenting of the mid RCA. (c) This is the angiogram of the LAD after primary stenting of the RCA. The lesion at the mid-segment of the LAD looked less severe. (d) In 5/2025 patient underwent coronary angiogram and showed wide patent mid segment of the LAD. The lesion at the mid LAD happened most likely due to compensatory hyperdynamic contraction of the left ventricle due to acute occlusion of the RCA.

Hemodynamic collapse following culprit artery revascularization In the primary intervention of patients with STEMI, the non-infarcted myocardium often increases its contractile activity to compensate for the loss of function in the infarcted region. In this case, a patient with an anterior wall myocardial infarction due to acute occlusion of the LAD artery presented with a diminutive RCA and a severe ostial stenosis at the origin of a large obtuse marginal (OM) branch. Pronounced hypercontractility was observed in the LCX and OM. Immediately after LAD revascularization, global left ventricular contractility declined, leading to a redistribution of coronary flow favoring the LAD territory and a concomitant reduction in perfusion to the LCX. The OM branch subsequently occluded at its origin, resulting in sudden cardiac arrest. Although an intra-aortic balloon pump and an Impella device were deployed, they failed to reverse the ensuing cardiogenic shock. This case highlights the importance of assessing potential flow redistribution – and the associated myocardial wall dynamics – in the non-culprit artery prior to primary PCI, as well as at both culprit and non-culprit arteries following acute opening of the culprit lesion (Videos 13.2 to 13.8).

Video 13.2 Patient came with anterior wall myocardial infarction. The right coronary artery was dominant and patent.

Video 13.3 The left anterior descending artery closed at the proximal segment.

Video 13.4 A wire crossed the lesion and positioned at the diagonal.

Video 13.5 A wire was positioned at the opening to the LAD.

Video 13.6 The LAD was seen open up to the apex.

Video 13.7 The patient developed hypotension, a spider view of the coronary angiogram showed acute occlusion of the obtuse marginal (OM).

Video 13.8 An intra-aortic balloon pump was inserted first while waiting for the Impella and the angiogram showed better flow to the LCX and OM. Even so, patient continued to deteriorate even after the Impella.

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CHAPTER 14

Interventions in Patients after Coronary Artery Bypass Graft (CABG)

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Patients who experience a recurrence of ischemia after coronary artery bypass graft (CABG) surgery have lesions in diverse anatomic distributions: saphenous vein graft (SVG), internal mammary artery (IMA) graft, radial graft, gastroepiploic graft, native arteries, or proximal subclavian artery before the IMA graft. Planning for percutaneous coronary interventions (PCIs) depends on the types of conduits (native artery, arterial or SVG) or the locations of the conduits (ostial, body, or at the anastomotic sites) and the degree of degenerative changes in the grafts [1]. The clinical and technical problems encountered during PCI of SVG are listed in Table 14.1.

Table 14.1 Clinical and technical problems during PCI of SVG

Problem	Corrective measure	Adverse outcome
Diffuse disease	Long stent	High rate of restenosis
Thrombus	Thrombectomy	Distal embolization
Degenerated SVG	Distal Protection	Distal embolization
Restenosis	Use of DES	High rate of restenosis
Retrograde embolization		CVA, distal organ emboli in SVG ostial lesion

Very Early Postoperative Ischemia (<1 Month)

The most common cause of ischemia within hours or days of surgery is acute vein graft thrombosis (60%). Other causes are incomplete surgical revascularization (10%), kinked grafts, and stenoses of the native artery distal to the insertion site and at the proximal or distal anastomotic sites, spasm or injury, or insertion of an arterial graft to a vein causing arteriovenous (AV) fistula.

Early Postoperative Ischemia (1 Month–1 Year)

Recurrent angina between 1 month and 1 year after the surgery is most often due to peri-anastomotic stenosis, graft occlusion, or de novo SVG stenosis at any sites due to fibrous intimal hyperplasia. Recurrence of angina at about 3 months postoperatively is highly suggestive of a distal graft anastomotic lesion and should, in most cases, lead to an evaluation for PCI.

Late Postoperative Ischemia (>3 Years after Surgery)

At this stage, the most common cause of ischemia is due to the formation of new atherosclerotic plaques in the SVG. However, these plaques have less fibro-collagenous tissue and calcification, so they are softer, more friable, of larger size, and frequently associated with thrombus.

SHARP THINKING

Selections of Patients

PCI offers a less invasive alternative for revascularization in symptomatic post-bypass patients including many who were not candidates for repeat surgery because of significant comorbidities (pulmonary and renal failure, old age, malignancy) as well as the potential complications of a reoperation (injury to a patent IMA graft, sternal dehiscence). Patients who can undergo PCI with acceptable risks are those with patent arterial grafts that would be jeopardized by reoperation, patients with relatively small area of ischemic, symptom-producing myocardium, and patients with no arterial or venous conduit available for graft. The status of the left anterior descending (LAD) artery and its graft significantly influences the selection process because of its impact on long-term outcome and lack of survival benefit of repeat surgery to treat non-LAD ischemia. A patent left internal mammary artery (LIMA) to LAD improves the safety and so favors the selection of PCI in the right coronary artery (RCA) or left circumflex (LCX) artery distributions. Therefore, selection of lesions for PCI must be based on careful analysis of the probabilities of initial success, complications, and long-term safety and efficacy compared with surgical strategies and medical therapies.

Indications for Surgical Revascularization

Reoperation is frequently recommended for a severe disease of a vein graft to the LAD. Multiple vessel involvement, absence of a patent graft to LAD, small number of patent grafts, severe vein graft disease, and reduced left ventricular ejection fraction (LVEF) are factors more likely lead to repeat CABG (Table 14.2) [1].

NATIVE CORONARY INTERVENTIONS

One year after bypass surgery, patients begin to develop new atherosclerotic plaques in the graft conduits or to show atherosclerotic progression in the native coronary arteries. Whenever possible, PCI to the native coronary artery lesions should be performed first because of their lower rate of restenosis. Approaches to native vessel sites in post-CABG patients include the treatment of protected left main disease, chronic total occlusion, or distal native artery via venous or arterial grafts.

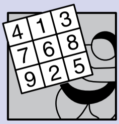
Table 14.2 **Anatomic factors influencing revascularization decisions in post-bypass patients**

Often lead to PCI	Often lead to CABG
Patent arterial graft (especially LAD)	Diseased SVG to LAD
or >2 patent grafts	Ejection fraction: <35%
1–3 culprit lesions	>3 culprit lesions
Inadequate conduit	Multiple SVG lesions
	Available arterial conduits
Ejection fraction: >35%	
Difficult surgical access	
*Posterolateral target vessel	
*Mediastinal scarring secondary to radiation, infection, or pericarditis	
*Prior muscle transfer closure of unhealed sternotomy	
Future cardiac surgery anticipated	
*In situ prosthetic valve	
*Mild to moderate aortic or mitral valve disease	

SAPHENOUS VEIN GRAFT INTERVENTIONS

One to three years after surgery, patients begin to develop atherosclerotic plaques in the SVG, and after 3 years, these plaques appear with increased frequency. At the early stage, PCI of the distal anastomosis can be accomplished with good long-term patency (80–90%). PCI of the proximal and mid-segment of the vein graft was highly successful at 90%, with a low rate of mortality (1%), periprocedural myocardial infarction (MI) and repeat CABG (2%). The rate of periprocedural MI was approximately 13%. The length of time since CABG was an important factor for restenosis as was the location of the lesion.

GAME PLAN



When evaluating the SVG lesions for intervention, the operators must consider possible consequences of distal atheromatous embolism, considering that the entire lesion and accompanying thrombus may be fragmented, dislodged, and embolized. Also, the relatively high subsequent coronary event rate and restenosis potential must be considered into this decision. It is reasonable to perform PCI to SVG if native vessel has chronic total occlusion or ACC type C lesions (severe tortuosity or severely calcified lesion) [1]. A meta-analysis including 52 893 patients suggest that routine use of embolic protection devices (EPD) during SVG intervention is not associated with a reduction in all-cause mortality, major advanced cardiovascular events, MI, or target vessel revascularization [2]. Routine use of EPD in contemporary real-world practice does not show any apparent benefit [2]. Based on these results, the 2018 European Society of Cardiology Guidelines on myocardial revascularization downgraded the use of EPD in SVG intervention to class IIa [3]. The 2021 American College of Cardiology/American Heart Association guidelines for coronary artery revascularization give a class IIa indication for using EPD during vein graft intervention when technically feasible [4].

Intervention of the Aorto-ostial Lesion

There is not much difference in the technique of PCI for aorto-ostial lesion of the SVG as compared to native vessel aorto-ostial lesion. However, because of higher incidence of fibrotic changes, calcification, and more recoil, a question for the need of prior debulking followed by stenting or stenting alone of the aorto-ostial lesion arises. Cutting or scoring balloons are usually sufficient and should be the first line of action. However, in recalcitrant-calcified lesions, rotational atherectomy (RA) might be utilized. Extra care needs to be demonstrated when using RA, due to tortuosity in most SVGs. In a reported case, the guide catheter was intubated deep into the vessel, so that the RA burr would not have to go through a tortuous segment, and a successful result was achieved [5]. The technical concern during PCI of large and bulky aorto-ostial lesion is the antegrade and retrograde embolization.

Intervention in Degenerated SVGs

The lesions that are bulky or associated with thrombus are considered high risk. The complications include distal embolization, no-reflow, abrupt vessel closure, and perforation. Hence, preventive approaches such as mechanical thrombectomy and distal EPD have been devised because distal embolization cause non-Q wave MI and increasing long-term mortality (Table 14.3). In diffusely degenerated grafts, a strategy of "spot" stenting can be utilized instead of long-stented segments, which can lead to a higher degree of distal embolization. In the case of perforation of SVG, tamponade is rare owing to the extra-pericardial course of the grafts and extensive post-pericardiotomy fibrosis. However, localized tamponade due to pericardial adhesions can cause hypotension. Additionally, mediastinal hemorrhage or perforation into right atrium has been reported [6].

Table 14.3 Advantages and disadvantages of distal protection devices

Advantages	Disadvantages
Balloon occlusive devices	
Easy to use	No antegrade flow
Aspirate large and small particles	Balloon-induced injury
Reliably trap debris	Not as steerable as PTCA wire
More tolerable with intermittent occlusion	Difficult to image during procedure
	Balloon can move during PCI
Distal embolic filter devices	
Preserve antegrade flow	May not capture all debris
Contrast imaging possible throughout procedure	Difficult to evaluate the retrieval of the debris during procedure
	Filters may clog
	Delivery catheters may cause embolization before filter deployment
	Cannot remove emboli intermittently in order to relieve overload
	Filter wire entrapment and may hook on stent during retrieval

Interventions of the Saphenous Vein Graft

In general, in search for the location of the insertion site, the more posterior the destination of the left-sided grafts, the higher they are located in the aorta. The top graft generally goes to the distal LCX, and the lowest graft goes to the LAD. Most left-sided grafts arise in a cranial direction from the aorta. Right coronary grafts are usually directed caudally and rightward in the ascending aorta [1].

GAME PLAN

If a small stent is deployed in a friable and fragile atheromatous segment of an SVG, further attempts to recross it with a large balloon would increase the risk of stent embolization. Deployment of a too-large stent would cause distal embolization due to excessive plaque extrusion, a reason similar to why aggressive post-dilatation with a balloon should be avoided. The length of the stent should be longer than the measured length of the lesion. The reason is the soft atheromatous content of a plaque will be squeezed farther and rearranged along its length due to pressure by a stent. When multiple stenting is planned, the distal stent is deployed followed by the proximal one. This strategy is to avoid recrossing the newly deployed stent. However, if there is a very tight proximal lesion, then crossing it can cause distal embolization of debris. The proximal tight lesion can decrease distal contrast flow and so hampers the optimal visualization of stent position and deployment. The risk and benefit of each strategy (to stent a distal or a proximal lesion first) should be assessed well before embarking on a selected path.

Tips and Tricks

****Guides for left bypass grafts** The Judkins right (JR) coronary or left coronary bypass (LCB) or hockey stick guide are better and effective for grafts arising anteriorly (the LAD and diagonals). The Amplatz left (AL) and the LCB guides also provide the best backup for grafts arising in the inner curvature of the aorta (to the LCX). Guide engagement is best achieved by advancing the guide into the ascending aorta at the level of the aortic cusps and then gently withdrawing the guide with clockwise rotation to orient the tip to the ostium in the right anterior oblique (RAO) view. When the tip of the guide catches the ostium, the guide is then advanced to obtain optimal backup (Figure 14.1).

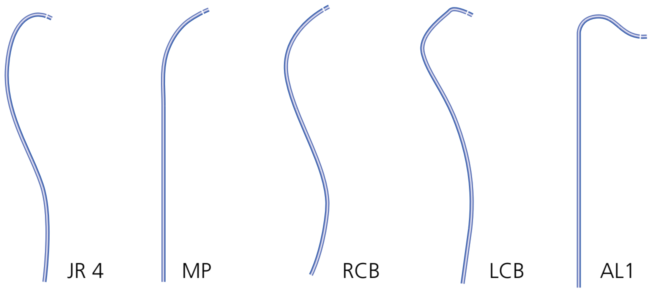


Figure 14.1 Guides for bypass grafts. For grafts of the right coronary artery: Judkins right (JR) 4, multipurpose (MP), right coronary bypass (RCB) guide. For the left circumflex/obtuse marginal vein graft: JR 4, left coronary bypass (LCB), or left Amplatz (AL) 1 guide. For the left anterior descending artery vein graft: JR 4, LCB, or AL 1. For the left internal mammary artery: JR 4 or left internal mammary artery (LIMA) guide.

****Guides for right bypass grafts** The Multipurpose (MP) guide usually provides excellent support for the usual caudally directed graft to RCA. The MP guide is best engaged using a counterclockwise rotation. Caution must be exercised that the MP guide does not deeply intubate the graft especially, if an ostial lesion is present. For the grafts arising from the outer curve of the aorta (usually to the RCA), the JR guide is the best to provide excellent coaxial alignment. Engagement into the ostium is achieved by advancing the guide into the aorta while making a clockwise rotation in order to point its tip toward the right, in the LAO projection, or the outer curvature, and then it is slowly turned counterclockwise to engage the graft with its tip pointing down. The right bypass graft points caudally; the right modified Amplatz will cannulate the ostium of the graft with its tip pointing down. If the aorta is relatively large, a posteriorly located RCA graft may be difficult to reach with a MP or JR guide but an AL will usually be successful in this situation.

***Balloon angioplasty for vein grafts** The lesion predilatation with balloon usually not needed or should be avoided due to higher chance of distal embolization, unless there is a severe lesion that hinders the stent to cross or proper positioning due to occluding distal flow by the stent at the tight lesion. If predilatation is needed for severe lesion, the balloons are generally sized 1:1 to venous grafts and inflated with low to nominal pressure. Long (30–40 mm) balloons can be used when the lesions are long and bulky or when thrombus is present. Cutting or scoring balloons are useful in calcified and/or fibrotic lesions.

****Stenting for vein grafts** The SVGs have a high degree of elastic recoil that can be overcome by stenting. Aorto-ostial vein graft lesions are most often treated with placement of stents (Figure 14.2). Non-dilatable aorto-ostial or distal anastomotic lesions have been successfully treated with rotational or directional atherectomy followed by drug-eluting stent (DES) [5].

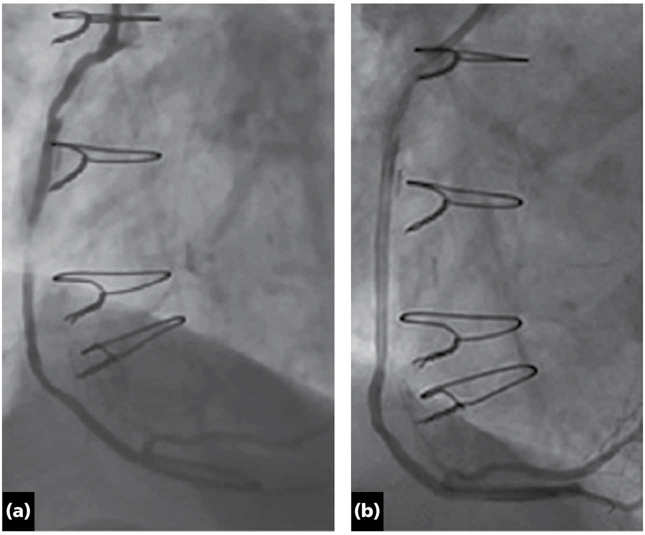


Figure 14.2 (a) Saphenous vein graft to right coronary artery before stenting. (b) Widely patent saphenous vein graft to right coronary artery after direct stenting.

WARNINGS

Mismatch and Risk of Stent Dislodgement During PCI at the Insertion Site

Problems with interventions at the anastomotic site include tortuosity of the arterial segments proximal and distal to the insertion site, difference in diameter of the segment proximal and distal to the target lesion, the degree of size mismatch between the distal vein graft and native vessel, and the angle of insertion of the vein graft into the native vessel. In case of stenting at the anastomotic site, the proximal part of the stent can be bigger, so the stent can have a funnel shape and is easier to dislodge backward. The size of the balloon is the size of the native segment distal to the insertion site [1].

PCI TO THE ARTERIAL GRAFTS

Balloon angioplasty and stenting are feasible in arterial in situ (left or right IMA) or free arterial grafts removed from the radial site. In PCI of IMA grafts, a hydrophilic steerable wire is helpful in the presence of tortuosity or severe calcification. Care must be taken to ensure that there is short guide length (90 cm) to reach distal sites with extra-long (145 cm) balloon catheters, or the guide can be shortened and capped with a flared, short sheath one size smaller.

Tips and Tricks

****Cannulation of the LIMA graft** On many occasions, the JR guide can easily engage the subclavian artery because its primary curve is less acute. A left subclavian arteriogram in RAO or anterior–posterior (AP) projection is recommended first. Then, a JR diagnostic catheter is exchanged for the IMA guide over a 0.038-inch wire. The usual view for cannulation of the LIMA is the AP view, with the patient’s arms down by the side. Selection of the subclavian artery is achieved by placing the guide, with or without the wire protruding, around the arch beyond the origin of the desired artery. The guide is then gently withdrawn and rotated counterclockwise to direct the tip superiorly until the wire or guide tip enters the subclavian origin. An angled hydrophilic wire may facilitate passage through a tortuous subclavian. The guide can then be advanced over the wire beyond the origin of the IMA, which is usually situated inferior to the thyrocervical trunk and distal to the vertebral artery. Small flush injections of contrast and gentle withdrawal of the guide can identify the location of the ostium. Gentle counterclockwise rotation of the tip directs it anteriorly and enables it to enter the IMA selectively. If it is difficult to see the ostium, a 60° left anterior oblique (LAO) or 45° RAO projection will elongate the aortic arch, allowing excellent visualization of the origin of the IMA, so that the guide tip can be engaged with precision.

Ipsilateral Radial Approach

The LIMA or right internal mammary artery (RIMA) can be approached by the radial artery access if the takeoff and proximal course of the two IMAs are descending vertically or internally. Using the femoral approach works better if the IMA originates from the vertical limb of left subclavian artery instead of the horizontal limb.

Tips and Tricks

*****Engaging the IMA guide with a wire** If the IMA is difficult to engage, a hydrophilic or a very steerable soft 0.014-inch wire can be used to super-select the IMA. It then functions as a rail for cannulation of the guide. This has been necessary more commonly in the right IMA with the tip of the guide nearby. Be very gentle when cannulating the IMA because it is prone to spasm and dissection. Intracoronary nitroglycerin or verapamil can be given generously. If the subclavian artery is very tortuous, guide cannulation can be achieved through the ipsilateral radial approach.

*****Engaging the RIMA with a pigtail catheter** After a failure of engaging the very tortuous right subclavian artery from the femoral approach and the brachial approach with standard IMA catheter, a new approach with a pigtail was tried. A 5-Fr pigtail catheter (Boston Scientific, Boston MA) was placed distally to the RIMA ostium, and a long 0.014-inch coronary wire (Choice PT Extra Support, Boston Scientific, Boston, MA) was advanced through the catheter. The more the catheter was moved distally, the more the loop of the pigtail catheter straightened. With this maneuver, in the LAO 50° view, the curvature of the pigtail could be adjusted to intubate the RIMA ostium selectively. The wire was advanced into the distal part of the vessel across the lesion. Then the pigtail catheter was exchanged for an IMA guide for PCI. This technique using a coronary wire in a 5-Fr pigtail catheter allows the tip of the catheter to be shaped according to any specific anatomy [7].

*****LIMA guide** The VB-1 catheter was developed as a modification of a pigtail catheter. The diagnostic version of the catheter has a shape that is similar to the proximal two-thirds of the curve of a standard pigtail catheter. Proper technique during use of the VB-1 catheter is important. After obtaining access to the left subclavian artery, typically with a JR catheter, a 175-cm length, 0.035-inch wire is positioned well beyond the origin of the LIMA and used to exchange for the VB-1 catheter. The wire is removed, and the catheter is flushed in the usual manner. The curvature of the distal tip of the VB-1 catheter allows it to be directed inferiorly. The slow withdrawal of the catheter toward the origin of the LIMA will allow the tip to cannulate the LIMA passively, and because of its flexible design, the catheter tip characteristically assumes a coaxial position in the proximal LIMA. If the LIMA arises anteriorly from the subclavian artery, gentle counterclockwise rotation while withdrawing the catheter directs the tip anteriorly toward the ostium of the LIMA, again achieving a coaxial position in the vessel [8]. The VB1 Guide is particularly useful to engage LIMA from the left radial artery without much manipulation.

PCI Through a LIMA Graft

Attempting PCI through an IMA graft is associated with four major technical challenges. First, IMA grafts may be difficult to engage. Second, IMA grafts can be long and interventional equipment may not be long enough to reach the target lesion. Third, IMA grafts can often be markedly tortuous, which not only may make wiring difficult but it also causes pseudolesions. Fourth, the antegrade IMA graft flow may cease after wiring [9]. It is worthwhile knowing if the native LAD is patent with severe stenosis or a CTO because, in case of damage to LIMA, the native LAD could become a target of PCI.

The first challenge, engaging the IMA, can be addressed by using various guides (such as IMA, VB1, or JR 4) and occasionally using a wire as a rail for pulling the guide into the IMA ostium. Alternatively, a diagnostic catheter may be used to engage the IMA ostium and insert an exchange length 0.014-inch coronary wire in the LIMA, followed by an exchange of the diagnostic catheter for a guide. If all else fails, an ipsilateral radial or brachial approach would allow IMA graft engagement [9].

The second challenge, reaching the target lesion in patients with long IMA grafts, could be addressed by using a shorter guide, shortening the guides, or using a longer shaft balloons and stents [9].

The third challenge, difficulty wiring the IMA, may be addressed by using hydrophilic, polymer-jacketed or transitionless wires, flexible microcatheters, such as the Transit (Cordis), Prowler (Cordis), Progreat (Terumo Medical Corp., Summerset, New Jersey), Finecross (Terumo), MicroCross and Renegade (Boston Scientific), Turnpike LP (Teleflex), and Caraval and Corsair XS (Asahi Intecc), over-the-wire balloons, or deflectable-tip catheters, such as the Venture catheter (St. Jude Medical, Minneapolis, MN), although the latter has a stiff shaft and may cause pseudolesions [9]. Addressing the fourth challenge (antegrade flow cessation after wiring) can be difficult. Although antegrade IMA flow cessation after wiring is usually caused by vessel "kinking" and pseudolesion formation, it can also be caused by dissection. In case of absence of landmarks which can be used for positioning the balloon or stents (clips, sternal wires), remove the wire over a flexible microcatheter to minimize the LIMA "accordioning" and to restore antegrade flow to allow visualization.

Tips and Tricks

****Use of a "dual-guide technique"** In this technique, a second arterial access is obtained and a second guide is used to engage either the native target coronary artery (if it is patent) or another bypass graft that supplies the target artery. The second guide can be used either for balloon and stent delivery or lesion visualization. The "dual guide" technique has limitations. First, it requires that the target native coronary artery be supplied not only by the IMA graft but also by another vessel. If the target vessel is supplied only by the IMA graft, then immediate wire removal may be required if the patient develops IMA occlusion with angina, electrocardiographic changes, or hemodynamic instability. An alternative solution in those cases would be to perform antegrade PCI of the native coronary chronic total occlusion, using LIMA injections to help direct and verify the position of the antegrade wiring into the true distal lumen [10].

*****How to overcome the problems with pseudolesions in tortuous LIMA** During PCI of a lesion in the tortuous LIMA graft, the wire may cause pseudolesion. As there was no flow through the LIMA, the angiographic assessment of the angioplasty result was difficult. Exchange the angioplasty wire with a flexible-shaft Transit catheter. Once the Transit catheter was in place, and the wire was removed, the LIMA assumed its normal tortuous contour, thus leading to resolution of the "accordioning" of the vessel. Injection of contrast though the guide (with the Transit catheter in place inside the LIMA in order to maintain a channel for wire access) permitted visualization of the entire LIMA and allowed angiographic assessment of the angioplasty lesion site [9].

ACTION POINTS

Intervention of IMA Graft

1. Angiography of the subclavian or the IMA in patients who are anticipating CABG if there is a $\geq$20 mmHg difference in blood pressure between the two arms.
2. Angiography of the subclavian artery in post-CABG patients with angina.
3. In evaluating the LIMA, sometimes a 90° lateral view might be the only view that shows the distal anastomosis adequately.
4. Watch out for spasm and pseudostenosis of LIMA when instrumenting that vessel.
5. Watch for deep guide intubation of the LIMA. Closely observe the pressure tracing. Do not inject contrast into the LIMA if unsure of the position of the guide. Deep intubation may cause dissection.
6. For radial graft, liberal use of intracoronary vasodilators is important as radial graft tends to spasm easily.

PREVENTION OF DISTAL EMBOLIZATION

Distal Embolic Protection Devices (EPD)

Distal filter wire devices have distinct advantages over occlusive balloons because distal coronary flow is not compromised during SVG stenting and they are technically less challenging to use. However, there are some disadvantages. First, smaller atheromatous debris can pass through the filter wire. Furthermore, this filter may not be able to seal the distal coronary vessel completely, leading to the passage of significant amounts of debris into the distal coronary bed. Due to the larger crossing profile, the passage of a filter across a lesion can be difficult or impossible. The need for predilatation with an undersized balloon may itself lead to distal embolization. It also requires an appropriate landing zone from the lesion site for filter deployment in the distal SVG, which should be neither too small nor too large (Figure 14.3a,b)**.** In the very distal or anastomotic lesions, deployment of these filters is not feasible due to inadequate landing zone. Finally, these filters can be trapped in the stent after or during the procedure, which can lead to significant dissection, stent crimped, perforation, and need for urgent CABG for device retrieval [11].

Proximal Protection Devices

Proximal occlusive devices have also been used to prevent no-reflow. With this system, there is a complete cessation of flow in the SVG achieved with inflation of a balloon proximal to the lesion and a static column of contrast is obtained after which the stent can be deployed. Following stent deployment, this allows complete aspiration of particles of all sizes after PCI or stenting of the lesion before restoring flow with proximal balloon deflation [11].

Advantages and limitations One of the advantages of using proximal occlusion devices is the fact that no bulky device needs to cross the lesion. Furthermore, lesions with an inadequate distal landing zone for filter wires can be easily treated with a proximal protection device. The major disadvantage of this device is similar to that of a distal occlusive device where there is a complete cessation of coronary flow that can lead to ischemia and hemodynamic instability. Furthermore, this system is technically challenging and costly, and it requires 8-Fr sheaths. Finally, ostial or proximal lesions cannot be treated with this device [11]. Currently, the proximal occlusive devices are not used and not available in the market.

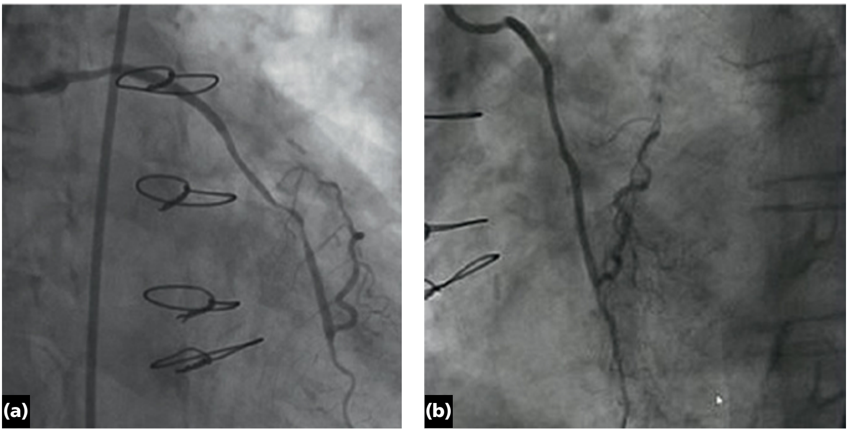


Figure 14.3 (a) A saphenous vein graft to the obtuse marginal branch before stenting. The branch is too small for an embolic protection device to go through. (b) The patient had direct stenting without any problem.

Use of Guide Extensions for Thrombectomy

The Guideliner (Vascular Solutions, Minneapolis, Minnesota), Guidezilla (Boston Scientific, Natick, MA), Telescope (Medtronic), Guidion (Interventional Medical Device Solutions), or Heartrail (Terumo) can be advanced further into the SVG in the presence of a large thrombus [12]. A large syringe is hooked up to the Tuohy-Borst, and aspiration is performed while the guide extension catheter is advanced or pulled back within the SVG. Aspiration should be continued while the guide extension is removed from the guide, which should also be allowed to "bleed-back" to ensure that all thrombus is cleared before further PCI is performed.

Tips and Tricks

****No-reflow with distal filter devices** During PCI of SVG, the filter can be filled with thrombotic and atheromatous material, and the distal flow can be cut off. After predilating angioplasty of an SVG lesion, repeat angiography may show no-reflow with the contrast holding up at the filtering device. The differential diagnoses are distal embolization despite the use of distal EPD, or that the filter wire was "choked" with embolized atheromatous materials. Therefore, aspiration thrombectomy should be performed to retrieve the debris from the overloaded filter. The tip is to fill the aspiration thrombectomy catheter syringe with saline. During injection, the fluid agitate the filtered materials, so they can be sucked out by vacuum aspiration (Figure 14.4a–e).

****Improvised distal protection device** In a laboratory without the availability of a dedicated distal EPD, a deflated over-the-wire balloon is advanced beyond the index lesion (e.g. the advanced coronary expansion [ACE] balloon, Boston Scientific, Boston, MA). Inflate it to obstruct flow and perform angioplasty. Ensure that the patient can tolerate the ischemia due to inflation of a balloon. After angioplasty, advance a large transport catheter with many side holes and aspirate the debris from the distal blood column [13]. This strategy cannot be applied to PCI with stenting because the balloon would be trapped if not removed prior to stenting. After positioning and inflation of the distal balloon before performing PCI, inject a column of contrast into the lumen to mark the location of the balloon and the proximal end of the column should be around the lesion to be dilated. While performing PCI, if the distal column of contrast does not move and there is no contrast seeping distally, then it is assured that the balloon is being kept immobile and the distal protection is intact.

SHARP THINKING

Technical Problems with Distal EPD

Two main problems remain with distal EPD technology. The first problem is that the size of the protection devices requires either predilatation or dottering of the target lesion which can cause distal embolization itself prior to the deployment of the distal EPD. In complex lesions, the "buddy wire" technique and small-sized balloon predilatation may be required. The second problem is the inability to protect both native branches when distal EPD has to be deployed in the native vessel due to the proximity of the SVG lesion to the distal anastomosis. In such a case, there will be preferential flow diversion to the unprotected branch with exacerbated embolization to that branch. A potential solution is the placement of an occluding balloon in the unprotected side branch which will force the flow through the distal EPD-protected branch [14].

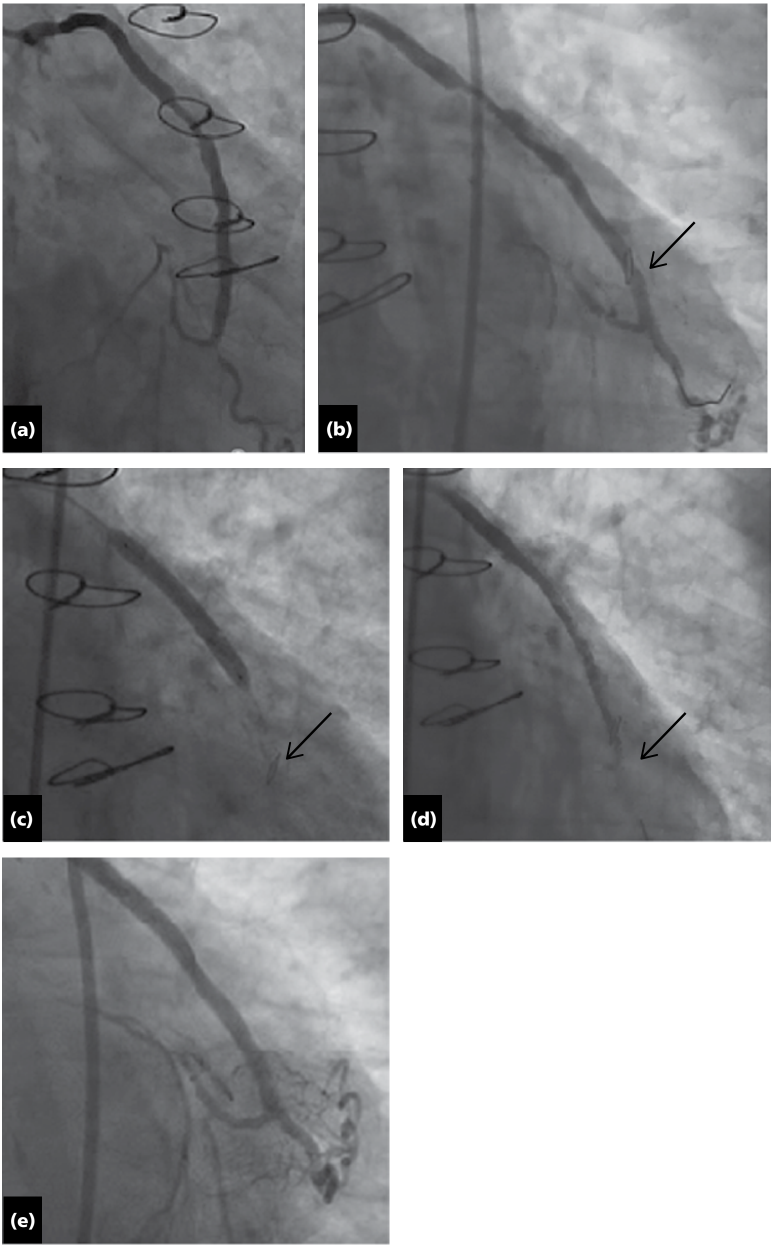


Figure 14.4 (a) A degenerated saphenous vein graft to the obtuse marginal branch before stenting. (b) A FilterWire was deployed distally (arrow). (c) A stent was deployed at the mid-segment while the FilterWire was seen distally. (d) After the stent was deployed, slow flow occurred at the beginning of the FilterWire (arrow). It happened because the filter was full of debris. (e) After the debris was suctioned out of the filter basket and the FilterWire was removed, the flow re-established.

Tips and Tricks

*****Bifurcating distal protection devices** Coronary angiography demonstrated double-vessel disease with a 70–90% stenosis in the proximal circumflex artery and a critical thrombus-containing lesion in a dominant RCA immediately proximal to its bifurcation to the right posterior descending artery (PDA) and right posterolateral artery (PLB). An 8-Fr JR 4 guide was positioned, and an intermediate wire was passed to the distal right PDA. A 1.5-mm X-Sizer thrombectomy device (Endicor Medical, San Clemente, CA) was placed proximal to the lesion, and aspiration was performed with only minimal benefit, as evidenced by limited thrombus extraction and improvement of the angiographic stenosis. At this point, an EPI filter wire (Boston Scientific, Santa Clara, CA) protection device was passed through the lesion and deployed in the large right PLB distal to the target lesion. Prior to the angioplasty in the target lesion, an ACE 1.5 × 20 mm balloon (Boston Scientific, Maple Grave, MN) was placed in the right PDA and inflated at low pressure, occluding the right PDA immediately distal to the bifurcation. Angioplasty was then performed to the RCA lesion with the inflated right PDA balloon preventing flow to that vessel with all flow diverted to the right PLB, which was protected with the prepositioned filter. The ACE balloon was removed, and the distal RCA was stented with an excellent angiographic result. The filter wire was then removed. As the PDA balloon was placed slightly distal to the bifurcation upon its removal, some slow flow was noted and successfully treated with intracoronary adenosine with TIMI 3 flow documented at the completion of the procedure in both branches of the RCA [14].

Tips and Tricks

*****Preventing no-reflow without the use of distal EPD** The use of EPD increases the procedure time and complexity and cannot be used in all SVGs due to vessel size (too small or large), anatomic location, and lesion complexity [15, 16]. The EPD is generally used in vessels between 3 and 5 mm in diameter. Study has shown that approximately half of the SVG lesions were not suitable for EPD; 42% and 57% of SVG lesions failed to meet the inclusion criteria for filter wire and balloon occlusion, respectively [17]. Even if EPD can be used, it may not completely seal the distal vessel and be unsuccessful in preventing distal embolization. Additionally, EPD use is associated with procedural complications, including vessel perforation, dissection, and device entrapment [15, 18]. When EPD is not available or not technically feasible for deployment, the following simpler techniques are associated with less distal embolization and no-reflow and improved clinical outcomes.

1. Intravascular imaging, such as intravascular ultrasound (IVUS) or optical coherence tomography (OCT)-guided vessel size and plaque characterization, is an important step for SVG intervention. Imaging would guide the appropriate sizing of balloon or stenting as oversizing would pose distal embolization.
2. Direct stenting in SVGs improves acute clinical outcomes such as less CK-MB and less non-Q wave MI [19].
3. Undersizing stents (<0.9) with higher stent/lesion length ratio reduce less plaque extrusion through stent struts shown by IVUS, less MI, and similar target vessel and target lesion revascularization [20].
4. Pretreatment with vasodilator therapy, especially before angioplasty/stenting, has been proven beneficial in preventing no-reflow phenomenon [21]. Studies showed that without visible thrombus, the prophylactic use of vasodilators including verapamil, adenosine, nicardipine, or nitroprusside with or without direct stenting is a safe and effective strategy to prevent distal microembolization and no-reflow phenomenon in SVG intervention [19, 22, 23].
5. Anecdotally, aspiration and low-dose intragraft tissue plasminogen activator has been used in SVG interventions by operators in selected cases with benefits to prevent or treat no-reflow where thrombus is visible.

Table 14.4 **Treatment of no-reflow (intracoronary doses)**

Adenosine 50–100 μg bolus for RCA and 100–200 μg for left main/intragraft
Verapamil 100–200 μg boluses up to 1000 μg with temporary pacer standby
Nitroprusside 100–200 μg bolus, up to 1000 μg total dose
Nicardipine 100–300 μg
Epinephrine 100–600 μg

6. Slow and prolonged inflation of balloon or stent reduce distal embolization.
7. Higher activated clotting time (ACT) during SVG intervention also reduces the no-reflow phenomenon.

****Effective injection of drug for no-reflow** The operator should be aware that agents administered through the guide may preferentially distribute to areas with retained flow rather than at the site of compromised flow. Therefore, when practical, drugs should be administered either through an infusion catheter placed distally or through the central lumen of an over-the-wire balloon catheter. Intracoronary nitroglycerin is usually suggested as the first-line agent, mainly to reverse epicardial vessel spasm, even if the blood pressure is reduced. Theoretically, nitroglycerin should have little impact on the arteriolar tone and hence on no-reflow since physiologically it produces little effect in the microvasculature. Generous doses of vasodilators can be utilized if nitroglycerin is ineffective. Vasodilators, when used in doses listed, have a significantly less impact on blood pressure when compared to nitroglycerin. Nicardipine is a long-acting vasodilator and causes less hypotension and thus is more effective (Table 14.4).

*****Treatment of no-reflow with distal blood aspiration** Aspirate slowly using a 50-mL syringe, while the guide is deeply advanced into the graft. The aspiration was effective in a patient because the slugging contrast from the vein was removed into the catheter. The result was excellent, the no-reflow phenomenon disappeared, and the ECG changes were normalized, concomitant with pain dissolution.

TREATMENT OF THROMBUS IN SVG

In the presence of confirmed large thrombus in SVG, the first option would be to perform thrombectomy If thrombectomy catheters are available. If thrombectomy fails, then medical treatment should be tried. Small thrombotic SVG lesions can be treated with direct stenting with other preventive measures of no-reflow as mentioned above. However, not all hazy lesions are thrombi and could be identified while wiring the lesion with a tactile feeling. A hazy spherical shape lesion in a degenerative graft could be mistakenly identified as a thrombus; while in reality, it turns out to be a heavy calcified plaque (Figure 14.5a–c).

Medical treatment of thrombus in SVG includes aspirin, P_2Y_{12} receptor antagonists (clopidogrel), and bailout use of glycoprotein 2b3a inhibitor (GPI) such as abciximab (intragraft bolus, eptifibatide, or tirofiban). In case of no response, intragraft use of fibrinolytic such as rtPA (5–10 mg) would be helpful. The patient is then maintained on intravenous heparin over the next 48 hours achieving a therapeutic PTT. However, data from large randomized trials are lacking. Prolonged infusion of GPI prior to PCI may allow for endogenous lysis of thrombus prior to intervention. This strategy is costlier because of long-term infusion of GPI. If a repeat angiogram at 48 hours after GPI does not show adequate resolution of the thrombus, then mechanical thrombectomy would be used.

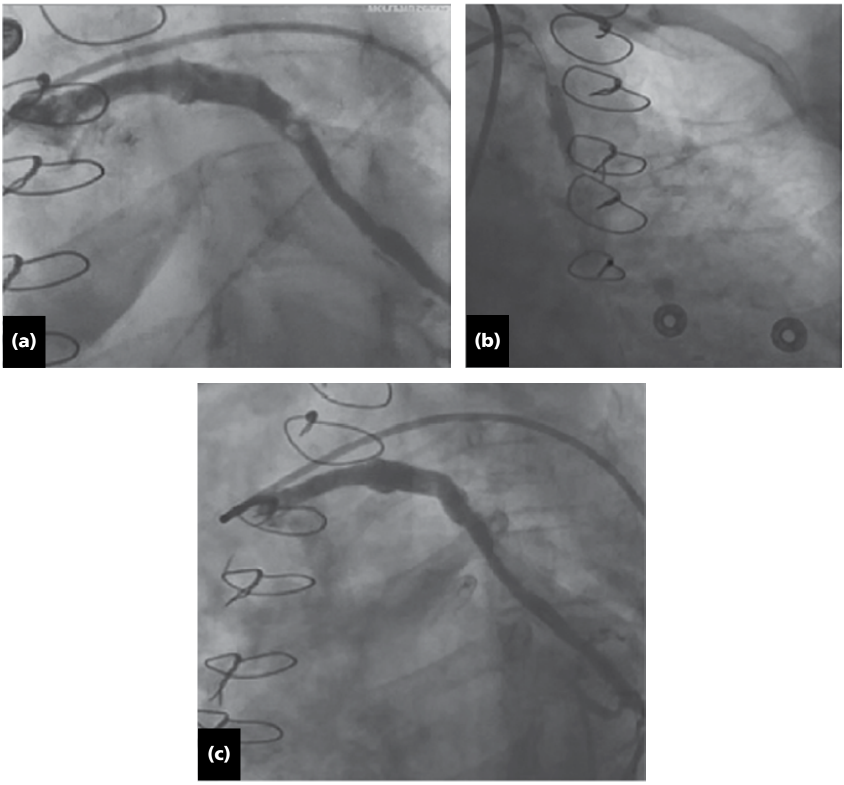


Figure 14.5 (a) A degenerated saphenous vein graft with a suspected thrombus at the mid-segment of the graft. (b) The wiring of the saphenous vein graft was difficult. Finally, a hydrophilic wire was successful in crossing the lesion. Sequential balloon pre-dilatation, starting with the smallest balloon, and then larger balloon angioplasty was performed. A buddy wire served as cutting wire. Eventually, a real cutting balloon was deployed. (c) When a stent was advanced, it could not cross the lesion. A wiggle wire was placed and finally a 4.0 × 12 mm stent crossed the lesion and was deployed.

Mechanical Thrombectomy

If mechanical thrombectomy is intended from the beginning, in cases of proximal thrombi, then they can be aspirated via guide or guide extension catheter. Smaller distal thrombi can be aspirated by manual aspiration catheters such as a Pronto, Fetch 2, Xpress-way, Priority one, QuickCat, or Export catheter. Mechanical thrombectomy such as Penumbra or AngioJet is a very effective method for thrombus removal if the thrombus is large. The Penumbra system (Cat RX, Penumbra incorporation) consists of a pump and rapid exchange aspiration catheter that continuously aspirates thrombus and blood into a canister.

The Aspiration Thrombectomy Device

To date, the series of devices that have been tested in clinical studies and are available on the market include the Penumbra aspiration system, Acolysis ultrasound thrombolysis device, the excimer laser, the transluminal extraction catheter, the AngioJet rheolytic thrombectomy device, the hydrolyser hydrodynamic thrombectomy device, the X-sizer helical thrombectomy device, and the rescue thrombectomy catheter. All these devices are rather complex to use, and not everyone is based on a rapid-exchange strategy; therefore, rendering their use during emergency procedures, in particular, at low-volume centers.

DEDICATED EQUIPMENT

E

Aspiration Thrombectomy

A dual lumen rapid exchange aspiration thrombectomy catheter with a 0.056-inch diameter extraction lumen. It has a rounded distal tip with a sloped extraction lumen to protect the vessel wall during advancement and is connected to a 30-mL locking vacuum syringe for extraction of the thrombus by the Venturi effect. Negative pressure should be maintained till aspiration catheter is removed from the guide. Back-bleeding is mandatory and will remove any residual thrombus fragments in the guide. Before the next passage, the aspiration catheter has to be flushed to remove thrombus fragments within the catheter.

DEDICATED EQUIPMENT

E

Rheolytic Thrombectomy

AngioJet rheolytic thrombectomy is a catheter-based method for thrombus removal. The catheter is attached to a drive unit with a piston pump that generates a high-pressure pulsed flow rate of 10 000 psi at 60 mL/min through a hypotube. The hypotube ejects its saline at a loop in the catheter tip. The jets of high-velocity saline are directed back into an exhaust lumen. This creates a vortex, or Venturi effect tip (Bernoulli effect) that fragments and aspirates thrombus and loose debris. Transient bradycardia develops with rheolytic thrombectomy catheter activation, particularly in right coronary or dominant circumflex lesions, and a right ventricular temporary pacemaker is recommended. Bradycardia is thought to be caused by the active release of adenosine from hemolyzed red cells. Transient ST elevation noted on the electrocardiogram during pump activation is usually due to the release of potassium from red cells and not active ischemia. However, based on the AngioJet in acute MI (AIMI) trial, concern with the use of this device for ST segment elevation myocardial infarction (STEMI) patients has been raised, primarily due to the increased mortality and larger infarct size in the AngioJet-treated patients [24].

Tips and Tricks

__**When a wire could not cross the lesion__ In this case, regular work horse wire would not cross the lesion. A hydrophilic wire would be used. Of course, filter wire will not cross the lesion. The lesion required sequential aggressive balloon predilatation. Then a buddy wire was used as a cutting balloon. After further lesion preparation with larger and higher pressure noncompliant balloon, still the stent would not cross. Then regular wire was exchanged with wiggle wire using wire extension and microcatheter. Finally, a 4.0 × 12 mm bare metal stent crossed the lesion, and with post-dilatation, using a 5.0-mm balloon, an excellent angiographic result was obtained with TIMI 3. Key points are rotablation would not cross and would be high risk for perforation due to calcified lesion at the bend. Filter wire could not be used. Cutting balloon is too bully to cross. So, hydrophilic wire, buddy wire, sequential balloon predilatation, and wiggle wire would be used in this type of lesion. Take-home point is not all thrombotic like a hazy lesion, which is also not a thrombus and may be a severely calcified lesion.

*****PCI for patients with STEMI within hours of CABG** Sometimes, shortly after returning from the operating room after CABG, the patient is found to have ST segment elevation in one of the areas just bypassed. Bypass angiography should be performed immediately. If there is a need for PCI, a full dose of unfractionated heparin could be used and is quite safe because during CABG with an open chest, the patient is fully heparinized and any bleeding vessels are fully cauterized. After the chest is closed, anticoagulation is reversed with protamine. More importantly, caution should be exercised in patients with a hemorrhagic output from chest tubes. During the intervention, extreme care is warranted, and balloon sizing should be conservative because of the possibility of suture line disruption and severe hemorrhagic complications [1].

If a graft is totally occluded, revascularization of the native vessel is preferable. However, if the native vessel is not a reasonable target, balloon angioplasty on the graft is also effective if thrombus formation is not extensive. Intracoronary thrombolytic therapy should be avoided due to a risk of mediastinal hemorrhage.

*****PCI in the subclavian artery** On many occasions, in a symptomatic patient after CABG, noninvasive studies can indicate ischemia in the distribution of a left or right IMA graft. The usual sites of obstruction include the IMA graft itself, the lesion at the insertion site, or the proximal subclavian artery. Obstructive lesion of the subclavian artery proximal to the origin of the LIMA graft can be found, although it is rare (Figure 14.1). Endovascular angioplasty followed by stenting of the subclavian artery relieves the ischemia in the territory supplied by the LIMA [25].

*****Perforation in SVG – no pericardial effusion with hypotension** In a case report after direct stenting, the angiogram revealed a diffuse rupture of the SVG with contrast leakage into the mediastinum. The patient became hemodynamically unstable with a very low blood pressure (50/30 mmHg). Volume resuscitation along with blood transfusion was used to stabilize the situation. Transthoracic echocardiography did not show any pericardial effusion. At the same time, three polytetrafluoroethylene (PTFE)-covered Jomed stents were deployed at 14 atm. Contrast extravasation occurred. Computed tomography (CT) scan showed a stable hematoma in the mediastinum without any active bleeding. However, this stable hematoma compressed the right ventricle causing hypotension. In cases of perforated SVG, when prolonged balloon inflation and reversal of anticoagulation fail to control the leak, PTFE-covered stent Graftmaster RX (previously Jomed stent, Abbot Vascular, Santa Clara, CA) or PK Papyrus single stent (Biotronic), polyurethane 5- or 6-Fr compatible and more deliverable) can be used, while coiling the graft can be used as a last resort [26].

*****Luxation of stent during aneurysm exclusion** As described in a reported case, the SVG to the LAD was patent; however, the sequential SVG showed a 95% ostial lesion followed by a saccular post-stenotic aneurysm that measured 12 × 13 mm^2. An 8-Fr JR guide and a 0.014-inch BMW wire (Guidant, Temecula, CA) were chosen for support and device delivery. The lesion was pretreated with a 2.5 × 10 mm followed by a 4.0 × 10 mm cutting balloon (Boston Scientific, Maple Grove, MN). Repeat angiography showed the enlarged entrance to the SVG and aneurysm without dissection, perforation, or rupture. The ostial SVG lesion, along with the post-stenotic aneurysmal segment, was stented with a 16-mm Graftmaster stent, which had been free-mounted onto a 4.0 × 20 mm Maverick 2 balloon (Boston Scientific). After stent deployment, the distal end of the covered stent was seen to have dislocated into the aneurysm properly, and the outlet of the stent was not in direct alignment with the rest of the SVG. In order to realign the covered stent, further stent coverage extending beyond the distal margin of the first stent was clearly necessary. Another free-mounted covered stent was deemed risky due to its relative rigidity, bulk, and potential for dislodgement. A decision was made to place a conventional, low-profile, and premounted stent. The choice for a longer stent was to secure mid-segment axial strength where there was no mechanical support from the adjacent vascular wall. Post-dilatation was performed with an excellent final angiographic outcome and minimal contrast extravasation at the distal end of the aneurysm [27].

ACTION POINTS

Despite advancements in SVG intervention, patients continue to experience a higher cardiac event rate. Success rate and long-term patency of PCI in the distal anastomotic lesions are exceptions. Contrary to native coronary arteries, the restenotic process in vein grafts does not plateau, and as a result, mild-to-moderate nontarget vein graft lesions are associated with recurrent ischemic events in about one-third of patients. If one moves from these relatively ideal candidates to the treatment of diffuse disease, recent total occlusions, the prospects for long-term patency, and clinical stability diminish, while the acute risk of thromboembolic MI, bleeding, and costs escalate. While continued study is needed to develop methods (membrane covered stent, brachytherapy, etc.) to prolong the functional life of degenerating venous grafts, and after thoughtful cost-conscious consideration of risks and benefits and resource consumption, day-to-day application of percutaneous strategies to these difficult problems must be approached with caution [1]. With the advancements in PCI for chronic total occlusion of native coronary arteries, revascularization of native coronaries might constitute a better approach in future.

NEW DISCOVERY

Using a novel dynamic angiography technique that highlights coronary flow patterns, it was observed that, following CABG, the predominant flow through IMA and SVG grafts occurs during systole. In one patient who underwent recent CABG with a left IMA graft to the LAD and an SVG graft to the LCX – while the RCA was not bypassed – the RCA lesion exhibited unexpectedly rapid progression. This deterioration appears to be associated with an increase in both the magnitude and timing of flow within the RCA. Specifically, the dominant flow in the RCA shifted from the typical diastolic phase to systole. This shift appears to synchronize the antegrade flow across all grafts and native arteries, likely to ensure concurrent perfusion of all left ventricular walls. The intensified systolic flow in the non-bypassed RCA may account for the accelerated progression of its lesion. Further investigation is warranted to better understand this hemodynamic transformation and its potential implications for graft planning and native vessel preservation, such as Videos 14.1–14.3.

Video 14.1 This is the right coronary artery with moderate to severe lesion at the mid-segment before open heart surgery (CABG). The dominant antegrade flow was in diastole as usual.

Video 14.2 This is the right coronary artery (RCA) with severe subtotal lesion at the mid-segment after bypass of the left anterior descending artery with a left internal mammary (LIMA) graft. The dominant antegrade flow in the RCA was in systole which was synchronized with the antegrade flow in the LIMA in systole.

Video 14.3 The dominant antegrade flow of the RCA after stenting was in systole.

Tips and Tricks for PCI to a Severely Calcified SVG to OM

Angiography showed a 99% severely calcified mid SVG to obtuse marginal (OM) lesion. A 6-Fr LCB guide was used to selectively engage the SVG to OM graft. Then, a run-through wire, sion blue wire, and whisper wire were tried to cross the SVG to OM lesion but were unsuccessful even with fine cross microcatheter support. Then, the LCB guide was removed, and AL1 guide was used for better support. Then, a Pilot 50 was used to cross the lesion after much wire manipulation and difficulty and placed distally. The Corsair Pro microcatheter was not able to cross the lesion. Then, a 6-Fr GuideLiner was used. The Corsair Pro microcatheter tried to cross the lesion but was not successful. Then a Turnpike gold catheter was tried but was unsuccessful in crossing the lesion. A Sapphire 1.0 × 10 mm balloon was used to predilate the lesion that was ruptured, which creates a microchannel, and distal flow was reestablished. Then, serial balloon predilatation was performed using 1.5 × 20 mm balloon, 2.0 × 15 mm balloon, and 2.5 × 15 mm balloon. Next a 3.0 × 15 mm noncompliant balloon was used to further predilate the lesion and assess for intravascular lithotripsy (IVL) with a good expansion. Then, a 3.0 × 12 mm shockwave balloon was used, and a shock was delivered; during the second shock, balloon was ruptured. Then, a new 3.0 × 12 mm shockwave balloon was used to predilate the lesion, and another four shock cycles were applied. Then, an Eagle Eye IVUS catheter was used to assess the vessel anatomy. The distal vessel reference diameter was 3.5 mm with an area of 9.5 mm^2, and proximal vessel diameter was 3.6 mm with an area of 10 mm^2. Then, a 3.5 × 23 mm stent was advanced and deployed, and a 3.75 × 15 mm noncompliant balloon was used to post-dilate the artery with minimal residual and TIMI 3 flow.

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CHAPTER 15

Bifurcation Lesion

Debabrata Dash, Hung M. Ngo, Marco Zuin, Thach N. Nguyen, and Shao Liang Chen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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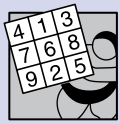
CHALLENGES

Currently, performing percutaneous coronary intervention (PCI) for bifurcation lesions presents significant challenges due to the highly variable bifurcated anatomy and the extent of myocardium at risk. While these anatomical factors shape the design of clinical trials aimed at identifying the optimal PCI strategy, additional challenges emerge as the procedure progresses. First, plaque composition – including smooth muscle cells, fibro-elastic content, and the characteristics of ostial lesions – can lead to increased recoil and a higher risk of dissection, potentially compromising both the side branch (SB) and the main vessel (MV). Second, intervention in either branch frequently results in plaque and carina shift, leading to new lesions. Third, stent metal accumulation often causes significant residual stenosis at the SB ostium and distortion of the distal portion of the MV stent. Many of these procedural complications are not evident on baseline angiography and may remain undetectable even after the procedure, making it impossible to quantify them in a predictive mathematical model for comparing different bifurcation PCI techniques [1]. Due to these procedural complexities, patient-specific factors, and numerous uncontrolled variables, no consensus exists on the optimal treatment strategy for bifurcation lesions. As a result, these lesions are often treated conservatively, leading to greater residual stenosis – especially at the SB ostium – and an increased risk of late restenosis [2].

GAME PLAN



When treating a bifurcation lesion, the first and perhaps most critical decision is determining whether to stent only the MV or to intervene on the SB as well – either with simple balloon inflation or by reserving the option to stent the SB if the outcome is suboptimal. This decision follows a thorough evaluation of the MV and SB lesions and the bifurcation angle.

SB intervention carries risks, particularly when the SB has disease at its origin, when the MV lesion is close to the SB ostium (leading to potential carina shift), or when the bifurcation angle is shallow (<45°) (Figure 15.1). However, any SB >2.0 mm should be preserved, making it essential to first address the following questions:

- Does the SB need wire protection?
- Does the SB require balloon dilatation?
- Is a stent necessary for the SB?
- If stenting is required, which technique is most appropriate?

A key challenge in any bifurcation PCI technique is ensuring adequate SB access, maintaining a satisfactory final SB ostial opening, and delivering the antiproliferative drug from the drug-eluting stent (DES) [3].

To achieve this, a comprehensive strategy must be devised, considering both the MV and SB. The **provisional T-stenting** approach is the most commonly used strategy. However, in true bifurcation lesions – where both the MV and SB are large, the SB has diffuse proximal disease rather than focal ostial disease, or the SB supplies a functionally significant area (e.g. providing collateral flow or supporting papillary muscles) – a planned two-stent strategy may be warranted. Techniques such as the **crush technique, double kissing crush, T-stenting, and the culotte technique** are appropriate in these cases [4].

The **provisional T-stenting** approach remains the preferred strategy. The MV stent is implanted and optimized using the **proximal optimization technique (POT)**. If the SB result is inadequate, wires are exchanged, and the SB is treated with **sequential kissing balloon inflation (KBI) or POT–side–Re-POT** [2, 5, 6] (Figure 15.2).

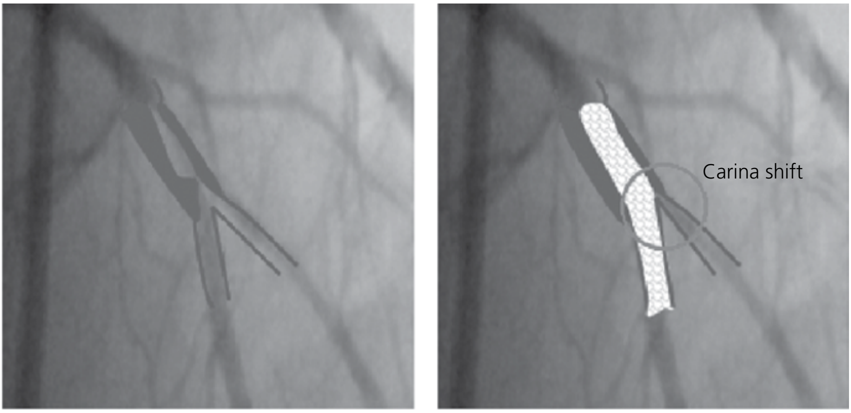


Figure 15.1 Carina shifts. After deployment of the stent, the carina moves proximally.

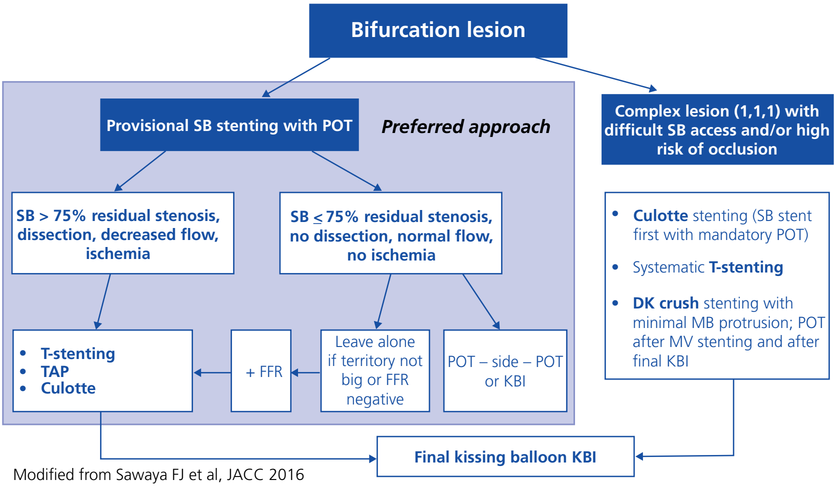
Tips and Tricks

How to select a double stent technique The current double stent techniques are the culotte, the crush technique, variants of the crush technique, the T technique, and the V or simultaneous kissing stent (SKS) technique. V or SKS can be used for bifurcations with a large proximal MB, such as LM stenosis. If there is no stenosis in the LM, stenosis in the ostia of both the left anterior descending artery and the circumflex artery can be treated with V stenting. Currently, SKS is not frequently performed due to relatively unfavorable angiographic and clinical outcomes. Due to the formation of a long metal carina in the proximal MV, the risk of restenosis or ST may be relatively high compared with other double stent techniques. The advantages and disadvantages of each stent technique are listed in Table 15.1.

SHARP THINKING

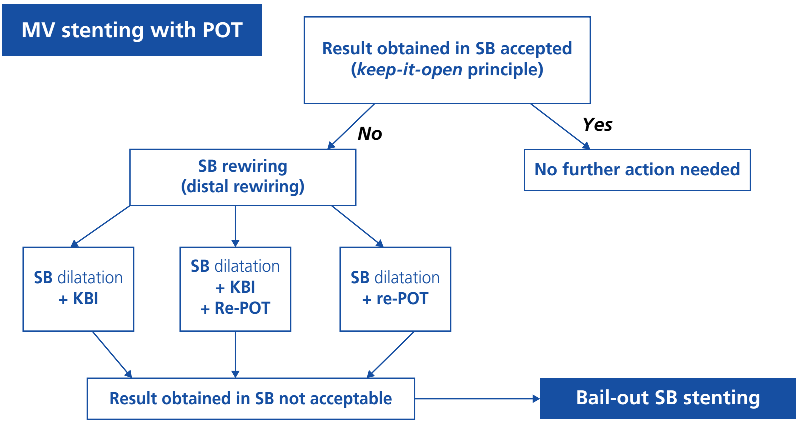
Discriminating Anatomy

The bifurcation angle plays a crucial role in PCI for bifurcation lesions. Studies have shown that a T-angle >70° increases the risk of complications. Patients with highly angulated lesions treated using the crush technique have demonstrated higher long-term mortality. Additionally, a steep bifurcation angle is significantly associated with an increased risk of abrupt vessel closure, SB occlusion, and a higher failure rate in recrossing the SB after MV stenting [7].


Bifurcation lesion
Provisional SB stenting with POT
Preferred approach
Complex lesion (1,1,1) with difficult SB access and/or high risk of occlusion
SB > 75% residual stenosis, dissection, decreased flow, ischemia
SB ≤ 75% residual stenosis, no dissection, normal flow, no ischemia
Culotte stenting (SB stent first with mandatory POT)
Systematic T-stenting
DK crush stenting with minimal MB protrusion; POT after MV stenting and after final KBI
T-stenting
TAP
Culotte
+ FFR
Leave alone if territory not big or FFR negative
POT – side – POT or KBI
Final kissing balloon KBI

Modified from Sawaya FJ et al, JACC 2016

(a)


MV stenting with POT
Result obtained in SB accepted (keep-it-open principle)
No
Yes
SB rewiring (distal rewiring)
No further action needed
SB dilatation + KBI
SB dilatation + KBI + Re-POT
SB dilatation + re-POT
Result obtained in SB not acceptable
Bail-out SB stenting

Modified from Lassen JF et al, Eurointervention 2017

(b)

Figure 15.2 (a) Strategy for a bifurcation lesion. (b) Strategy for main vessel stenting with the proximal optimization technique (POT). SB: Side branch; POT: proximal optimization technique; TAP: T stenting and small protrusion technique; FFR: fractional flow reserve; KBI: kissing balloon inflation; DK: double kissing; MV: main vessel; MB: main branch.

GUIDE

With current generation low-profile balloons and stents, bifurcation PCI can be performed using 6- to 8-French (Fr) guides, depending on the technique. Provisional SB stenting can be achieved with a 6-Fr guide (inner diameter ≥0.07 inch), which also accommodates the simultaneous delivery of a monorail stent and balloon or two balloons for KBI. Techniques such as double kissing (DK) crush and step/balloon crush can also be performed with a 6-Fr guide.

Table 15.1 **Advantages and Disadvantages of Two-Stent Techniques**

	Advantages	Disadvantages
T-stenting/TAP	• Suitable for bifurcation angles >70° • Easy final kissing inflation	• Not suitable for bifurcation angles <70° • Geographic miss at the ostium of the SB or excessive protrusion in MV
Culotte stenting	• Suitable for bifurcation angles <70° • Complete coverage of SB ostium	• Excessive metal at proximal MV • Not suitable for diameter mismatch between two daughter vessels
Mini-crush stenting	• Complete coverage of SB ostium	• Difficulty for SB reaccess due to multiple layers of stents • Stent malapposition at the ostium of SB
DK crush stenting	• Complete coverage of SB ostium • Facilitated SB reaccess • Improved stent apposition	• Double kissing balloon inflation

TAP: T stenting and small protrusion technique; MV: main vessel; SB: side branch; DK: double kissing.

For more complex two-stent techniques, a 7-Fr (≥0.08 inch) or 8-Fr (≥0.09 inch) guide is required. Guides with strong passive support, such as extra backup or Amplatz, are preferred. If radial access does not permit the use of a larger guide, a dual-access approach using one guide from the radial artery and another from the femoral artery is a viable alternative.

WIRES

The choice of guidewire type (soft, stiff, string-type, or hydrophilic) and wiring strategy (which branch to wire first, etc.) depends on lesion anatomy. If a one-stent technique is selected, a wire may be left "jailed" in the SB during MV balloon angioplasty and stenting to serve as a landmark for rewiring through the side of the MV stent. The operator should use the highest steerability wire with which they are most familiar to optimize control and success.

Tips and Tricks

****Which branch to wire first?** To minimize difficulties with wire crossing and wire wrap, the more challenging branch – typically the SB – should be wired first, as it requires greater manipulation. The second wire will generally track along the first and should then be used to cross the MV lesion with gentle torquing (no more than a wrist rotation). The following are the best practices for wire management:

- Keep both wires separate to avoid entanglement.
- Use different-colored torque devices for each wire or create a shallow proximal bend on one wire for easy identification.
- Maintain wire organization by leaving them on the table in the same position as after crossing the lesion – do not tangle them during the procedure.
- Any crisscrossing of wires on the table will be transmitted distally once the first balloon is inserted.

In two-stent techniques, preventing wire wrapping is a primary technical concern when advancing devices into the MV and SB. Careful wire handling is essential to ensure smooth device delivery and procedural success.

****Step to facilitate SB wire removal** A nonhydrophilic wire is preferred for the SB to reduce the risk of shearing the hydrophilic coating upon removal. However, some operators still opt for hydrophilic wires based on personal preference. To prevent difficulty in removing a jailed SB wire, the MV stent should be deployed at a relatively low pressure, ensuring adequate wall apposition while allowing for higher-pressure postdilation after SB wire removal if needed. Another useful technique is to pull back the SB wire before deploying the MV stent, leaving only a short distal segment inside the SB. This minimizes the risk of entrapment while maintaining access to the branch.

****Dilating the MV in order to access the SB** The POT has become the preferred final step in provisional T-stenting, replacing routine final KBI [2]. The primary goal of POT is to restore the natural bifurcation geometry by expanding the proximal MV stent to its reference size (since the stent is sized according to the distal MV diameter). Additionally, POT helps neutralize carina displacement, reducing the risk of SB ostium compromise. Although POT is straightforward in concept, achieving proper execution requires precision. It involves inflating a short balloon, sized to match the proximal MV, just before the carina tip. Alternatively, rotational atherectomy (rotablation) with a small burr (1.5 mm) may be used to modify plaque configuration. If SB wiring fails, and the SB is large with significant ostial disease, the procedure should be aborted rather than proceeding with the assumption that the SB will remain open after MV stenting.

LESION PREPARATION

Predilatation of the MV before stenting is the standard approach for lesion preparation. However, routine predilatation of the SB is unnecessary and should be avoided due to several disadvantages. Predilating the SB increases the risk of dissection, which may necessitate SB stenting. Additionally, if the SB ostium is not scaffolded by the MV stent, predilatation can lead to a higher risk of restenosis. However, in cases of severe SB ostial stenosis, predilatation may be considered. If plaque debulking is needed, rotational coronary atherectomy is a potential option.

BALLOON ANGIOPLASTY

Balloon angioplasty is utilized for lesion preparation of the MV or SB in order to facilitate the stenting process.

Initial SB and MV Balloon Angioplasty

Both branches should be wired as previously described, followed by balloon inflation in the MV. Predilatation of the MV is a crucial step in lesion preparation and should be routinely performed in stable patients. However, routine predilatation of the SB remains controversial. It is recommended only in specific situations, such as difficult SB access, severe diffuse or calcified lesions, or compromised SB flow after wiring [6].

Practical Applications

The decision to predilate the SB depends on the intended treatment approach. For the one-stent technique with provisional stenting, predilatation of the SB is not recommended due to the risk of dissection, which could compromise SB flow and necessitate switching to a two-stent strategy. Additionally, the presence of a dissection flap may hinder the smooth insertion of a third wire into the true lumen. If the flap is near the bifurcation carina, it could prevent the ideal crossing of the distal stent strut. The basic concept of the one-stent approach is to "keep it open" (KIO), where the primary goal is to achieve MV stenting while focusing less on the anatomical outcome at the SB, as long as there is adequate antegrade flow down the SB [1].

The possibility of SB dissections also represents a challenge with the culotte technique because there is a need to rewire one of the branches to position a second stent. Therefore, when only the culotte technique is planned, gentle predilatation should be performed on the branch that needs to be rewired (preferably the less angulated branch) [1].

ROTATIONAL ATHERECTOMY

Lesion debulking with rotational atherectomy may be of particular benefit in smaller vessels, vessels that are heavily calcified, and those with significant ostial SB lesions (Figure 15.3).

GAME PLAN

In general, the largest and most important limb is wired first for rotational atherectomy with a small burr (e.g. a 1.5-mm burr for a 3.0-mm limb) to ensure a reliable lumen. If the lumen of the second limb is easily accessible, it can typically be reached by withdrawing the burr just proximal to the bifurcation, placing it on Dynaglide™, and advancing the wire directly into the branch. However, this maneuver is not recommended if the lumen of the second limb is difficult to wire. It's important to note that a second wire should not be present during rotational atherectomy, as the burr can ablate and sever the wire within the coronary artery.

Tips and Tricks

****An "off-label use" technique for rotational atherectomy** As a last resort, if a RotaWire™ cannot be advanced, an RG3 wire can be used to cross the lesion and perform a single-pass atherectomy with a 1.25-mm burr. Afterward, the RG3 wire can be exchanged for a regular RotaWire, allowing for an additional pass with a 1.5-mm burr. The RG3 wire is a 0.010-inch wire with a hydrophilic coating, which allows it to be used in place of a 0.009-inch RotaWire.

****Wire bias** Wire bias, which can lead to dissection and/or perforation, is a particular concern in SBs with an acute takeoff angle. This risk can be minimized by using a small burr and paying close attention to wire bias. It is important to consider the impact of wire bias when pulling or pushing a burr into or out of a lesion. A small burr that is pulled into a lesion by the wire will ablate significantly more tissue than a burr directed away from the lesion.

****Side-branch protection** Because SB compromise is rarely observed after rotational atherectomy, protecting branches with a second wire or performing predilatation of SBs may not be necessary. In fact, balloon angioplasty before rotational atherectomy should be avoided, as predilatation can cause dissection, which may preclude the use of rotablation. Since rotational atherectomy typically results in a suboptimal lumen, the procedure is generally completed with a KBI, which can usually be performed at low inflation pressures.

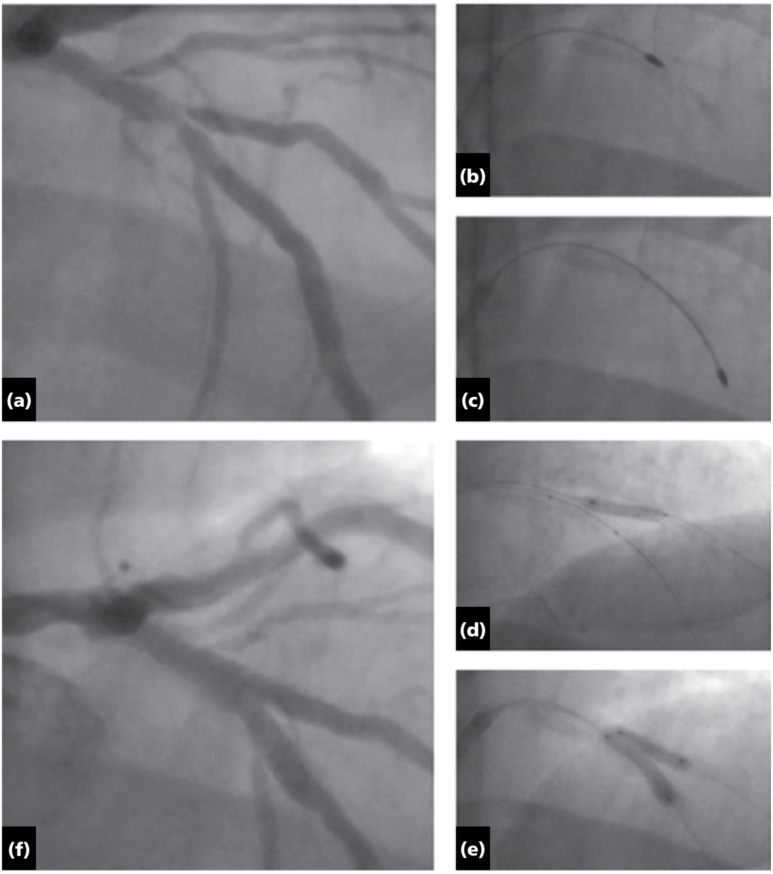


Figure 15.3 Lesion preparation with rotational atherectomy. (a) The left anterior descending (LAD) artery with a 90% proximal lesion and Medina 1,1,1 bifurcation lesion. (b) Rotational atherectomy of the diagonal performed with a 1.5-mm burr. (c) Rotational atherectomy of the LAD performed with a 1.5-mm burr. (d) Stenting of the diagonal. (e) The bifurcation lesion was stented in the double kissing mini-crush technique. (f) Final angiogram showed great results.

STENTING

GAME PLAN

The choice of technique is determined by the bifurcation angle, which may be <90°, approximately 90°, or retroflexed (>90° relative to the antegrade MV). Typically, the provisional SB stenting technique is the initial approach. For a wider distal bifurcation angle, T-stenting is the preferred choice. If the bifurcation angle is <70°, techniques such as DK crush, reversed crush, culotte, and T-stenting at provision (TAP) are all reasonable options (Figure 15.4).

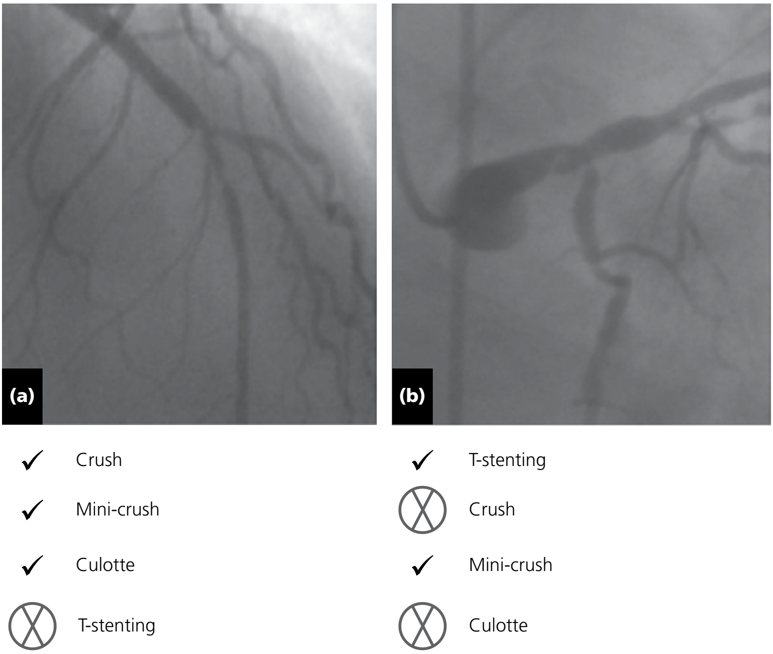


Figure 15.4 Influence of the bifurcation angle on the selection of technique for a bifurcation lesion. (a) Y shape; (b) T shape.

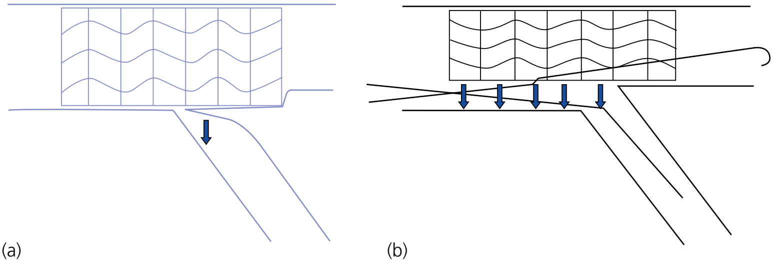


Figure 15.5 Sizing of the stent for the main vessel. (a) The main vessel stent should be sized according to the distal main branch diameter immediately after the bifurcation. (b) Postdilatation with proximal optimization technique (POT), or kissing balloon inflation, is required to optimize the proximal main vessel stent diameter.

Discriminating Differences

Selection of stent The two important criteria in stent choice are the stent design and the initial profile of the MV stent. The size of the MV stent is equal to the diameter of the main branch immediately distal to the bifurcation (Figure 15.5).

Open or closed cell design As the SBs are typically "jailed" by MV stenting, it is necessary to cross into the SB through the MV stent struts. This highlights the importance of understanding the differences in stent design and how dilatation of MV side cells impacts the outcome. In open-cell designs, the stent struts are stretched and displaced with SB balloon dilatation, resulting in a progressively larger opening as the balloon size increases. However, not all stents respond in the same way. In closed-cell designs, not all side cells open progressively with SB balloon dilatation. Different MV stent sizes and designs also result in varying maximal strut openings after dilatation into the SB. This is particularly important when dealing with larger SBs, as the maximal strut opening should not be significantly smaller than the SB diameter. If the opening is too small, stent struts may cross the SB ostium, potentially altering hemodynamics. Additionally, using a too-large balloon to stretch the SB strut may fracture the stent strut.

Stent deformation after side-strut dilatation It has also been shown that SB dilatation through an MV stent consistently causes narrowing of the MV stent lumen immediately downstream from the SB. This narrowing becomes more pronounced as the size and inflation pressure of the SB balloon increase. Redilatation of the MV stent lumen using a larger balloon can partially reverse this effect, leading to a reduction in the SB ostium size. This process is known as the POT [8].

Proximal Optimization Technique (POT)

The current most widely accepted strategy for provisional T-stenting, replacing routine final KBI, is POT [2]. (Figure 15.6).

The diameter of the MV stent should be selected based on the reference diameter of the distal segment, and any proximal stent apposition issues should be corrected with POT. POT is performed by inflating a short, mostly noncompliant balloon from the proximal edge of the stent to just proximal to the carina. The distal marker of the balloon should be positioned just before the carina. Proper balloon positioning is critical for achieving the desired result. If the balloon is positioned too distally, there is a risk of SB occlusion due to carina shifting. Conversely, if the balloon is positioned too proximally, it will have no effect on the stent struts at the SB. [6]. POT should be routinely performed in bifurcation stenting as it facilitates rewiring of the SB, lowers the risk of stent distortion caused by catheter collision, and enhances scaffolding of the SB ostium.

PROVISIONAL SIDE-BRANCH STENTING

GAME PLAN

Provisional SB stenting involves stent implantation in the MV and, if necessary, in the SB. If, during prestenting dilatation, the SB occludes, dissects, or experiences impaired flow, the threshold for SB stenting significantly decreases. Bailout stenting of the occluding SB is reasonable if its diameter is 2.5 mm or larger. After deployment of the MV stent and following the POT maneuver, if the flow in the SB is suboptimal, a wire and a balloon are passed through the side cell of the MV stent into the SB. Balloon angioplasty of the SB is then performed with high-pressure inflation using a 1:1-sized balloon to re-establish blood flow (Figure 15.2b). If the opening of the SB ostium remains suboptimal, a stent is advanced into the SB and deployed with its proximal margin at the origin of the SB. Final KBI is performed to correct any deformation of the MV stent after SB dilation. Alternatively, a small balloon (1.5 mm or 2.0 mm for stents 3.5 mm and larger) can be inflated at the ostium with low pressure (6–10 atm) to ensure sufficient flow in the SB without distorting the stent (Figure 15.6).

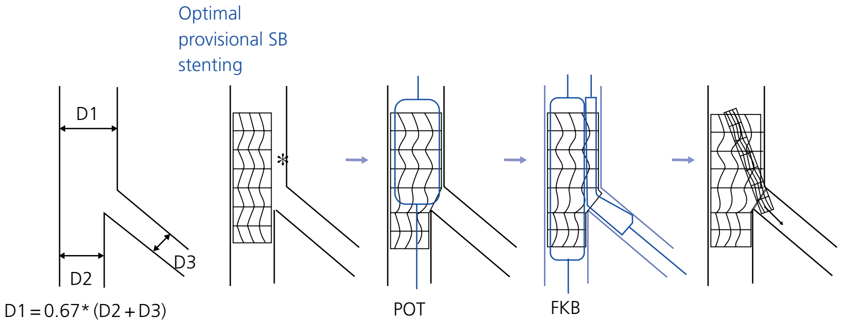


Figure 15.6 The proximal optimization technique (POT). Expansion of the stent at the carina, using a short oversized balloon that produces curved expansion of the stent into the bifurcation point and facilitates recrossing, distal recrossing, kissing inflations, and ostial stent coverage of the side branch. D: diameter; SB: side branch; FKB: final kissing balloon inflation.

SHARP THINKING

Advantages and Limitations

The provisional T-stenting technique carries the risk of not fully covering the SB ostium. To optimally scaffold the SB ostium, the wire should ideally enter the SB ostium through the most distal stent cell of the MV. With balloon inflation of the SB, this will create adequate scaffolding to overlap with the SB stent. Another technique to ensure coverage of the SB ostium involves protruding the SB stent into the MV, thereby creating a neocarina in the MV. However, this approach may increase the risk of stent thrombosis.

T-STENTING TECHNIQUE

In the case of a bifurcation lesion with an SB at a 90° angle, the traditional T-stenting technique is the most suitable approach. A wire is placed in both the MV and SB. A stent is first deployed in the SB, with its proximal edge at the origin of the SB, ensuring that it does not protrude into the MV. The SB wire is then removed. Next, a stent is advanced into the MV, deployed over-the-wire (OTW) across the origin of the SB. The MV stent is then recrossed into the SB, and the SB ostium is dilated to enlarge the stent cell opening before performing final KBI.

SHARP THINKING

Advantages and Limitations

T-stenting can yield excellent results when the SB originates at a right angle to the MV (Figure 15.7). However, when the bifurcation angle differs from 90°, the T-stenting technique carries the risk of either leaving an unstented gap at the origin of the SB or causing the SB stent to protrude into the MV (Figure 15.8).

MODIFIED T-STENTING TECHNIQUE

To better cover the SB ostium, the modified T-stenting technique is recommended. First, both branches are wired, and predilatation is optional. A stent is advanced into the SB, followed by a second stent into the MV, ensuring it covers the ostium of the SB. The SB stent is carefully

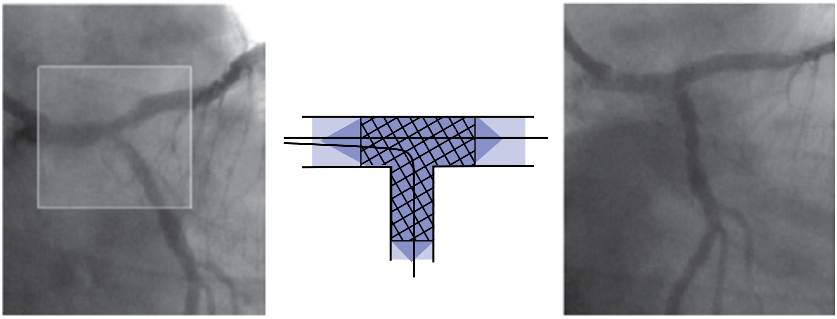


Figure 15.7 The T-stenting technique is best for a bifurcational lesion with disease extending proximal to the bifurcation and a side branch that has its origin at about a 90° angle.

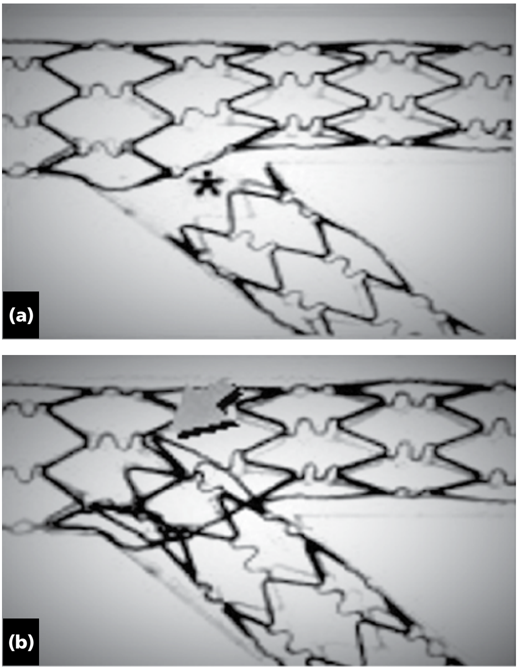


Figure 15.8 Gap and protrusion of struts in bifurcation stenting. (a) When the bifurcation angle is other than 90°, the T-stenting technique runs the risk of having an unstented gap at the origin of the side branch (SB) because the SB stent is deployed too distally. (b) If the SB is deployed too proximally, a portion of the SB stent protrudes into the main vessel, creating obstruction and increasing the risk of subacute thrombosis.

positioned at the SB ostium and deployed. Afterward, the balloon and wire are removed from the SB, and the MV stent is deployed. The SB is rewired, and KBI of both stents is performed (Figure 15.9).

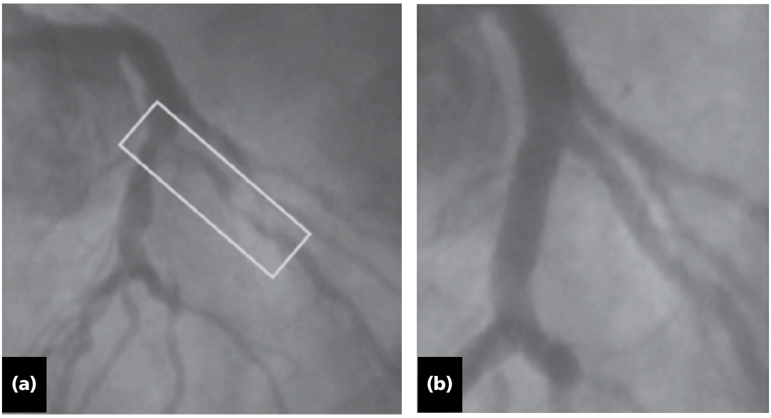


Figure 15.9 The modified T-stenting technique. (a) Before stenting. (b) After stenting.

SHARP THINKING

Advantages and Limitations

This technique enables precise positioning of the stent at the SB ostium. In the case of slight protrusion of the SB stent into the MV, the MV stent can push the SB struts into the SB during its deployment. The MV stent can be of any design, preferably with a large side cell to facilitate rewiring and dilatation of the SB.

The limitations of this technique include the need for a larger 7- to 8-Fr guide and its restriction to cases with near-90° SB bifurcations. However, in practice, more than three-quarters of all bifurcation lesions have angles <70°. Additionally, if the SB stent is implanted too distally, an uncovered gap may remain at the SB ostium (see Figure 15.8a). Another disadvantage is that both stents are positioned simultaneously, and movement of one stent can disturb the precise positioning of the other.

Practical Applications

The MV lumen should be well predilated to accommodate two stents without causing ischemia, ensuring good contrast flow to allow full evaluation of the positioning of both stents, including the proximal end of the SB stent at the SB ostium [9]. With a 7-Fr guide that can accommodate two stent catheters, the operator may experience some dampening of the blood pressure, although this issue is less noticeable with an 8-Fr guide.

THE T AND PROTRUSION (TAP) TECHNIQUE

GAME PLAN

The TAP technique is a modified version of the T-stenting approach. It involves stenting the SB with slight protrusion into the MV, using a noncompliant balloon in the MV to aid positioning. The SB stent can then be accurately placed at the ostium without protrusion. After deploying the SB stent, both balloons are pulled back to the proximal part of the MV, followed by a final KBI (Figure 15.10).

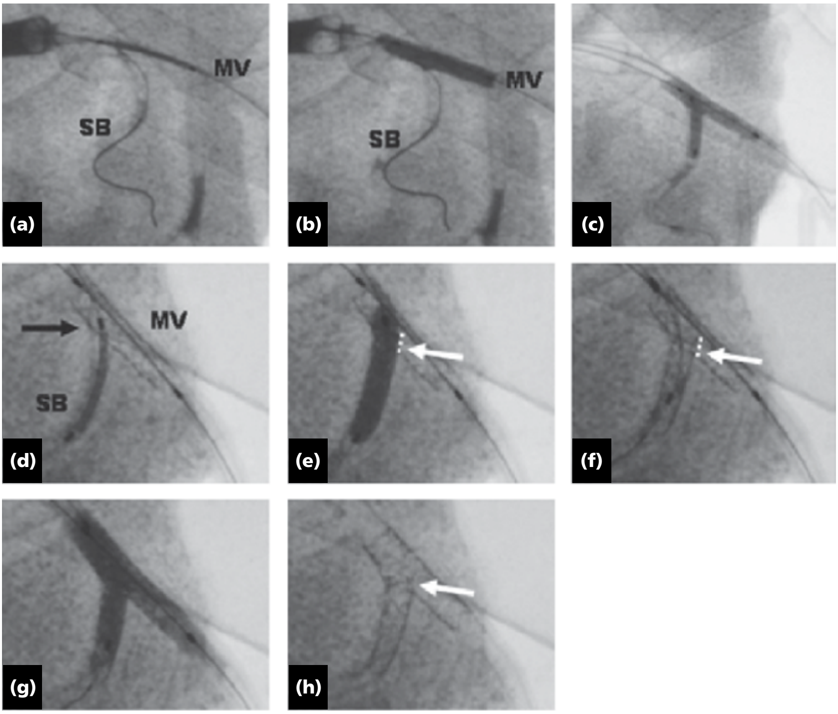


Figure 15.10 The TAP technique: angiographic images of in vitro TAP stenting. (a) Stent positioning in the main vessel (MV) with jailed wire into the side branch (SB). (b) Deployment of MV stent. (c) Kissing balloon inflation after rewiring of the SB. (d) SB stent positioning: the position of the SB stent is adjusted to fully cover the proximal (or upper) part of the SB ostium (arrow), while an uninflated balloon is kept in the MV. (e) SB stent deployed with the uninflated balloon into the MV. (f) After SB stent deployment, the balloon of the stent is slightly retrieved and aligned to the MV balloon. The arrow indicates the protruding SB stent's struts within the MV only at the distal side of the SB ostium. (g) Final kissing balloon inflation is performed by inflating simultaneously the SB stent's balloon and the MV balloon. (h) After kissing balloon inflation, the protruding SB stent struts are reoriented, resulting in a small, single stent strut, neocarina (arrow).
Source: Reproduced with permission from [11] / John Wiley & Sons.

SHARP THINKING

Practical Applications

If final KBI is planned, SB predilatation should be avoided. The reason for this is that, in coronary bifurcations, plaque is typically localized on the outer wall of one or both daughter vessels, with the flow divider (carina) almost always free of disease. After MV stenting, the carina (which is free of disease) shifts toward the SB ostium, facing the intact plaque on the outer wall of the SB (which was not disrupted by predilatation). As a result, during the next step (rewiring the SB), it is easier for the operator to cross into the SB through the distal stent strut at the tip of the flow divider (referred to as distal cross). Rewiring through this point ensures optimal scaffolding of the SB ostium after the final KBI. However, if final KBI is not planned, a stepwise strategy is recommended, with the first step being systematic balloon angioplasty of the SB, followed by MV stenting [10].

Advantages and Limitations

A drawback of the TAP technique is that predilatation of the SB may cause a dissection, which can hinder wire recrossing through the MV stent strut and increase the risk of crossing a proximal strut (proximal cross). This could result in deformation of the MV stent during subsequent KBI, raising the likelihood of needing provisional SB stent implantation. In such cases, to optimally scaffold the SB ostium, the provisional SB stent typically protrudes into the MV, creating a neocarina in the MV, with a potentially higher risk of stent thrombosis [10].

CRUSH STENTING

GAME PLAN

In the crush technique, stents are positioned in both the MV and SB, with the proximal part of the SB stent lying well within the lumen of the MV. It is crucial to ensure that the proximal edge of the MV stent is more proximal than the SB stent. The SB stent is deployed first, and then the balloon and wire are withdrawn while ensuring that the MV stent stays in position. The MV stent is then deployed, crushing the proximal part of the SB stent. The SB is rewired, and a final KBI is performed. Sequential balloon inflations are essential: first, the SB balloon (usually noncompliant) is inflated at high pressures (18–20 atm), followed by the inflation of both balloons together at medium to high pressures (10–15 atm) [12].

SHARP THINKING

Advantages and Limitations

The crush technique requires a minimum 7-Fr guide. One potential limitation of this technique is the movement of the MV stent during the withdrawal of the SB balloon and wire. Repositioning the MV stent may be challenging due to the protrusion of the SB stent struts into the MV [9]. The extent of SB stent protrusion into the MV classifies the classic crush technique into two types: "mini-crush" (1–2 mm) and classic crush (3–5 mm) (Figure 15.11). Given the potentially higher incidence of stent thrombosis, the mini-crush technique is preferred. Another concern is that the multiple stent layers may delay re-endothelialization after DES implantation. Additionally, bench studies have shown areas of suboptimal stent apposition and excess metal struts, which could disrupt laminar hemodynamics and cause flow stagnation, thereby increasing the risk of stent thrombosis.

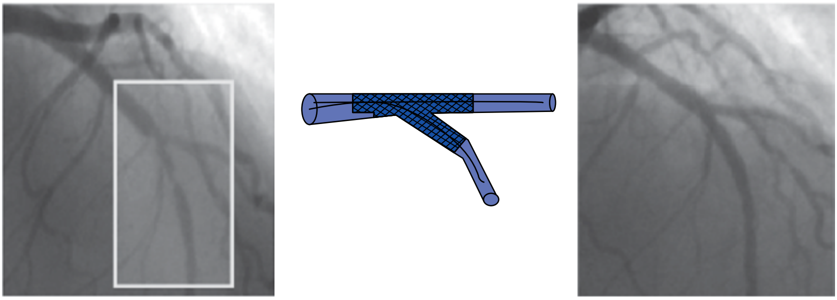


Figure 15.11 The mini-crush technique is best for a bifurcational lesion with disease extending proximal to the bifurcation and a side branch that has about a 60° angle to the main vessel.

DOUBLE KISSING (DK) CRUSH

GAME PLAN

In the DK crush technique, two wires are positioned in the MV and SB. The SB stent is positioned with its proximal end protruding 1–2 mm into the MV. The SB stent is deployed first, while another balloon is positioned in the MV. The SB wire and balloon are then removed. The MV balloon is positioned with its proximal marker in line with the proximal end of the SB stent. The MV balloon is inflated to approximately 10 atm, crushing the proximal portion of the SB stent. The MV balloon is then pushed distally. The SB stent is rewired, and a balloon is advanced into the SB stent. The first KBI is performed, expanding the SB orifice. The wire and balloon from the SB are removed again. A new MV stent is advanced, and the balloon is inflated to deploy the MV stent and further crush the proximal portion of the SB stent. The SB is rewired again, a balloon is advanced into the SB, and a second KBI is performed [13] (Figure 15.12).

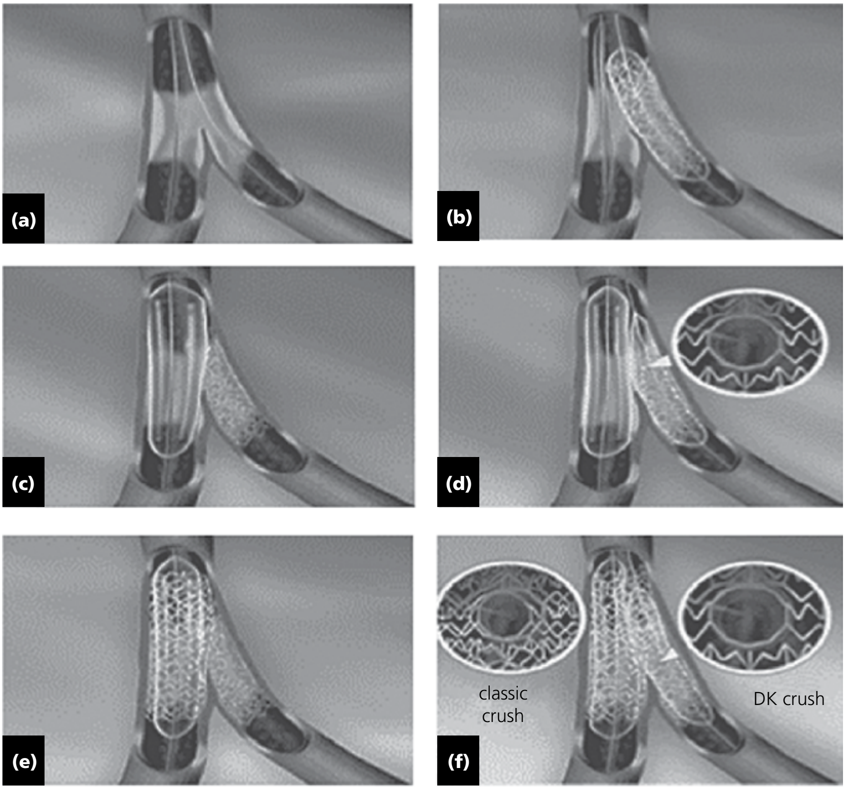


Figure 15.12 The double kiss (DK) crush technique. (a) Two wires are inserted into the lesions. (b) Deploy the side-branch stent first. (c) The balloon crushes the side-branch stent. (d) First kissing balloon inflation. (e) Deploy another stent in the main vessel. (f) Final kissing balloon inflations. The right-hand figure shows the larger opening of the side-branch ostium with the DK crush technique compared with the smaller opening of the side branch in the classic crush technique.

Tips and Tricks

****Crossing a balloon into the side branch** At first, the MV balloon is inflated at low pressure (around 10 atm) and crushes the SB stent in its proximal portion. The MV balloon is pushed distally. Rewire the SB and advance the balloon into the SB. If the balloon fails to cross the stent strut, advance a new, noncompliant balloon. If this is not successful, dilate the SB ostium in a stepwise fashion with a smaller semicompliant balloon. If still unsuccessful, inflate the MV balloon (which is positioned distally) as an anchor to stabilize the guide so that the SB balloon can cross into the SB ostium.

****Advancing the MV stent with an SB balloon as an anchor** If there is difficulty in advancing the MV stent, inflate the SB balloon in order to anchor the guide.

SHARP THINKING

Advantages and Limitations

The DK crush technique only requires a 6-Fr guide, similar to the balloon crush technique. The first and final KBIs are easily performed due to the presence of only one layer of stent struts across the SB ostium. DK crush is associated with a larger SB ostial opening, and its greater success is explained as follows: After the proximal segment of the SB stent has been crushed by the MV balloon, it becomes distorted and significantly unexpanded. The first KBI repairs the distorted proximal segment and fully expands the SB stent orifice. The MV stent is then deployed, and the inflated MV stent almost does not touch, or only barely touches, the partially repaired segment of the SB stent. With fewer metal struts at the SB ostium, recrossing into the SB stent and performing the second KBI is easier. In contrast, the classic crush technique not only makes rewiring and reballooning more difficult or sometimes impossible, but it can also cause more damage to the distorted SB stent if the wire ends up partially or completely under the SB stent. The main cause of suboptimal immediate and long-term results in the classic technique is the large metal ostial coverage gap. The additional second KBI in the DK crush technique is a key step to repairing MV stent distortion and enhancing strut scaffolding at the SB ostium [13].

REVERSE CRUSH

In the reverse crush technique, a stent is already deployed in the MV, and the SB is wired through the MV stent cell. After predilatation of the SB ostium, a stent is positioned in a way that ensures that the proximal part lies well within the MV. A balloon of the same size as the MV stent is positioned in the MV. Then the SB stent is deployed, and the SB balloon and wire are withdrawn. The SB stent is then crushed by the MV balloon. The SB is rewired, and the final KBI is performed.

SHARP THINKING

Advantages and Limitations

This technique is useful in two situations: (1) when it is believed that routine SB stenting may be avoidable, but the SB result is suboptimal after the MV stent is deployed; or (2) for patients who experience ongoing issues related to restenosis at the SB ostium following MV stenting alone [14].

SIMULTANEOUS KISSING STENTS (SKS)

The SKS technique is most suitable for easily accessible bifurcations with a large proximal reference diameter containing plaque and when both branches have similar diameters. The procedure involves wiring both the MV and SB, which ensures access to both throughout the entire process. Both stents are positioned side by side, creating a "double-barrel" configuration, and are deployed simultaneously, helping to minimize plaque shift. Keeping both stents parallel extends the carina of the bifurcation proximally.

The primary requirement for SKS is the size of the proximal vessel – it must be equal to or larger than 70% of the summed size of the distal branches. For example, if the SB is 3.0 mm and the MB is 3.0 mm, the MV must measure at least 4.2 mm ($0.7 \times [3+3] = 4.2$ mm).

Advantages and limitations The SKS technique is the simplest and most immediate approach for treating bifurcations when two stents are necessary. However, there are several limitations: it requires relatively narrow bifurcation angles and the use of large-sized guide catheters (minimum 7 Fr). Additionally, this technique does not allow for provisional stenting, forcing the operator to deploy two stents from the very beginning of the procedure. Other disadvantages include the following:

- Creation of a metallic carina with a large overlap of metal in the MV.
- Formation of a gap beneath the crossing point of the two stents.
- The double-barrel configuration makes endothelialization more challenging.
- Lifelong dual antiplatelet therapy may be required for the patient.
- If proximal dissection occurs, converting to a crush stenting technique or placing another stent becomes very difficult.

Tips and Tricks

****Perfect stenting** The operator must carefully align the proximal ends of the two stents during the procedure. Stent inflation should begin gently, starting with the SB stent, followed by deflation before inflating the MV stent. The final KBI is a crucial step to complete the procedure. If rewiring is necessary during the SKS procedure, the wire must be manipulated with great care within the stent rather than through the overlapping struts [15].

CULOTTE STENTING

In the culotte stenting technique, a stent is placed in one branch, followed by the placement of a second stent through a cell of the first stent into the opposing branch, with overlap of the proximal portions of both stents (Figure 15.13). Initially, wires are placed in both branches, and predilatation is performed either sequentially or simultaneously. The first stent is placed in one vessel, covering a segment both proximal and distal to the bifurcation, extending across the opposing branch. A second wire is then advanced through the deployed stent into the unstented vessel. Some operators prefer to leave the initial wire in the branch vessel during stenting of the first vessel to guide recrossing, although this can result in the risk of wire entrapment. Once the unstented branch is crossed with a wire, the branch is dilated with a balloon to open the stent cell in preparation for stenting. The balloon is then removed, and the second stent is advanced over the branch wire and positioned to cover the branch lesion while overlapping the proximal portion of the previously placed stent. After the wire in the first branch is pulled back before deploying the second stent, it is readvanced across the struts of both stents into the first vessel. Finally, balloons are advanced over both wires and inflated to complete the procedure with a final KBI.

Tips and Tricks

****Perfect stenting** During the final inflation, it is important to be certain that both balloons are within the proximal stent and that they are inflated at relatively low pressure, being careful not to oversize the overlapped balloons.

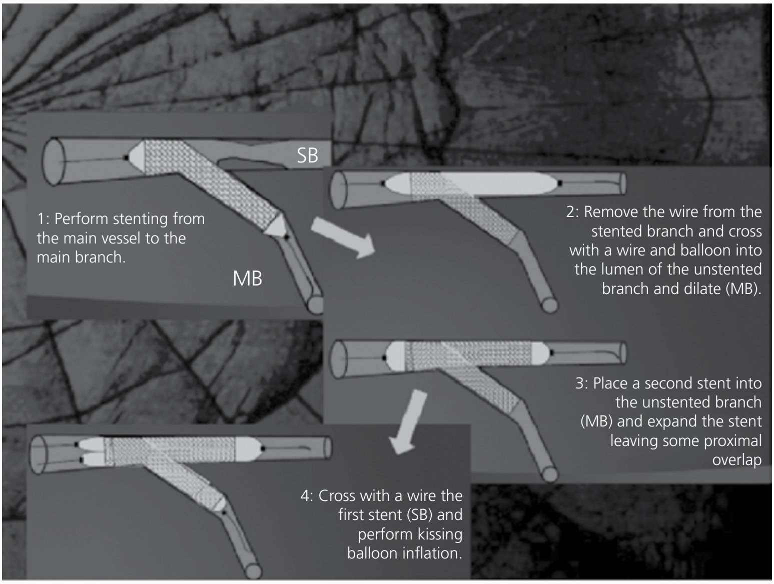

SB
1: Perform stenting from the main vessel to the main branch.
MB
2: Remove the wire from the stented branch and cross with a wire and balloon into the lumen of the unstented branch and dilate (MB).
3: Place a second stent into the unstented branch (MB) and expand the stent leaving some proximal overlap
4: Cross with a wire the first stent (SB) and perform kissing balloon inflation.

Figure 15.13 The culotte stenting technique.

****Which branch should be stented first?** Typically, the larger, more important branch is stented first, although the angulation at the bifurcation must also be considered. If there is significant angulation or heavy calcification, it may be preferable to stent the more angulated branch first to facilitate easier access to the opposing branch. If there is a significant dissection or occlusion in one branch, it should be stented first, as wire removal could be risky. Therefore, when the lesion remains T-shaped (indicating a bifurcation angle >70°) after wiring, and if access to the SB is difficult or the SB lesion is long or dissected, the SB should be stented first. When stenting the SB first, it is important to remember that visualization of the SB ostium can be challenging. Before deploying the stent, it is crucial to check the stent position with multiple views to avoid placing the SB stent too distally or proximally. Once both the MV and SB stents are deployed, attention can then be focused on the SB ostium.

INTERVENTIONS OF SIDE BRANCH

The frequency and severity of SB compromise can be reduced by balloon angioplasty, rotational atherectomy, or directional coronary atherectomy (DCA) of the SB prior to stent placement, although redilatation is often required after stent deployment. Compromise of small SBs (<2 mm in diameter) is typically not clinically significant and may not require any specific treatment. In the case of larger SBs that are compromised, a second wire can often be passed through the side struts into the affected SB. If the SB ostium is narrowed due to carinal shift, a relatively small balloon is usually sufficient to enlarge the SB ostium. However, if the SB ostium is compromised due to plaque shift, a larger balloon may be necessary to increase the SB size. In such cases, it is important to avoid distal SB dissection. For severe SB lesions that are unlikely to respond to balloon dilation, rotational atherectomy through the stent struts into the SB can be performed. In these cases, a small burr should be used to minimize the risk of complications.

Side-Branch Wire Entry

Some operators leave a wire in the SB during MV stent deployment to mark the site of the SB origin. After deploying the MV stent, a wire is advanced through the MV stent and carefully manipulated to enter the SB via the MV stent's side cell. It is crucial to avoid passing the new wire behind the MV stent; it must pass through a side cell of the MV stent into the SB. Proper wire positioning within the MV stent lumen is confirmed by the smooth, unobstructed passage of the wire beyond the MV stent. If the wire is positioned incorrectly under the MV stent, this is typically indicated by an inability to advance a balloon into the SB (Box 15.1).

BOX 15.1 TACTICAL MOVE

Best options for crossing a wire into the side branch

1. **First Best Option:** Reshape the tip of the wire
2. **Second Best:** Use a hydrophilic wire
3. **Third Best:** Use an OTW balloon
4. **Fourth Best:** Dilate the MV to make the side cell more enlarged (POT)
5. **Fifth Best:** Use a dedicated Venture or Crusade catheter

SHARP THINKING

Risk and Benefits of a "Jailed Wire"

Most of the time, a wire can be deliberately "jailed," meaning left in the SB while stenting the MV, particularly when the SB has a stenosis >50%. The "jailed wire" technique is part of the KIO concept for SBs, where any reasonably sized (≥2.0 mm) or functionally significant SB requires protection with an additional wire. This technique also helps modify the angle between both branches, converting a T-shaped bifurcation into a Y-shaped one, which facilitates easier rewiring. The presence of the jailed wire helps keep the SB open. Moreover, the absence of such a wire has been shown to increase the long-term risk of reintervention. In the case of occlusion, this wire (usually nonhydrophilic) can serve as a valuable landmark, aiding recrossing with another wire into the SB after MV stenting.

Tips and Tricks

****Where to cross the stent side cell: Ideal goal and real-life dilemma** Access to the SB through a stent strut is usually possible via two or three different cells (proximal, mid, or distal). The choice of cell can affect stent deformation, and the ideal approach is to cross through the most distal cell when wiring the SB. However, in real-world situations, if the stent cell is 1 × 1.5 mm wide, there will be three cells (1+1+1 = 3 mm) facing the SB ostium. The challenge is determining which cell to choose for recrossing. For example, if a 2.5 mm diameter SB has 70% ostial stenosis after MV stenting, this results in an SB ostium diameter of 0.7–0.8 mm. The operator must decide the ideal location to cross between the three stent cells. After dilating the most accessible cell, at least two or three struts will protrude into the SB ostium, which may help reduce the risk of in-stent restenosis. Additionally, the POT can aid in crossing the distal stent strut. This technique helps prevent carinal shift caused by an oversized stent, although it does not completely eliminate the risk of carinal shift.

SHARP THINKING

Where to Insert the Wire?

As the dimensions of a stent cell are 1 × 1.5 mm, there are 1 + 1 + 1 = 3 mm cells covering an SB ostium from which the operator has to choose which cell to recross. The classic teaching is to recross the most distal cell. In reality, with a 2.5-mm diameter SB with ostial stenosis of 70% after stenting, the new ostial SB diameter is 0.7–0.8 mm. In this situation, the operator has a large selection of cells to insert the wire into (Figure 15.14).

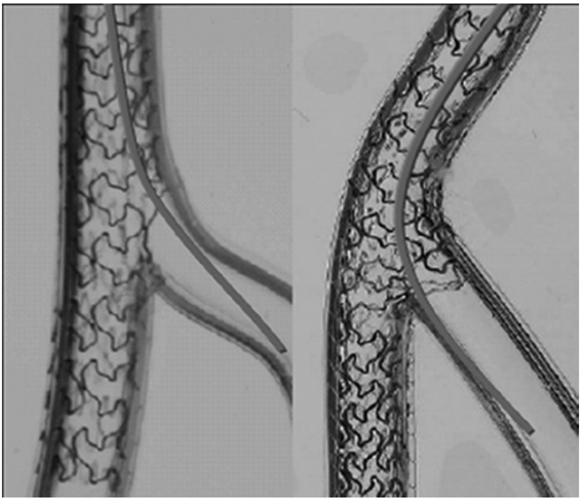


Figure 15.14 Insert the wire at the distal cell.

Tips and Tricks

****How to manipulate a wire to cross an MV side cell** At first, the wire should be shaped to approximately 90°; after the tip has been engaged within the struts at the origin of the SB, a slight backward movement with careful steering allows crossing of the tip into the SB:

1. In case of no success, reshaping of the tip with a wider, >90° curve should be attempted.
2. A hydrophilic-coated wire might encounter less friction in crossing the struts, but the risk of dissecting the SB increases.
3. If this also fails, consider stiffer tapered-tip wires (e.g. the Miracle wire series).
4. If, after MV stenting, the SB has diminished thrombolysis in myocardial infarction (TIMI) flow, or the angle is >70°, it is advised not to withdraw the jailed wire. The MV wire should be used to enter the SB with the jailed SB as a landmark.

****Use an OTW balloon to cross the side cell into the SB** In case of no success, a 1.5-mm OTW balloon or microcatheter can be advanced close to the origin of the SB to increase the support of wire crossing. This technique is especially useful for a reverse (>90°) angle of origin of an SB. The J tip is shaped manually, depending on the angulation of the SB, and the length of the tip should be equal to the diameter of the MV (Figure 15.15).

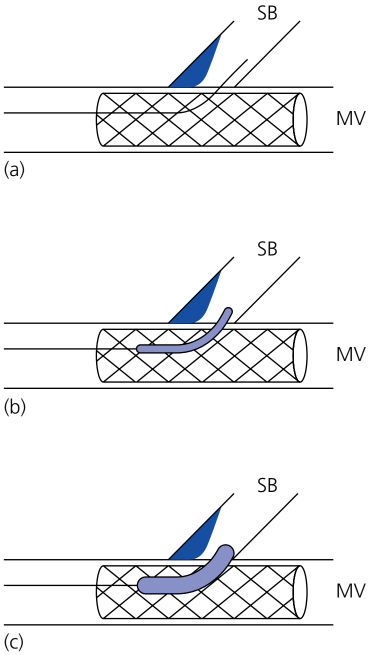


Figure 15.15 (a) Use an over-the-wire balloon to cross the side cell into the side branch (SB). (b) Try to cross the main vessel (MV) stent strut with a balloon on a fixed wire. This balloon has minimal transition between the wire and balloon. (c) If just the tip of the balloon crosses the side struts, inflate the balloon to open the side cell.

****Use a stiff wire to cross the side cell into the SB** If the distal bifurcation angle is wide, a stiff wire is needed to facilitate advancement. After insertion of a hydrophilic wire into the SB, a microcatheter or OTW balloon can be used for exchange with a nonhydrophilic wire.

****How to shape the wire tip** In an "extremely angulated" lesion, it is usually impossible to enter the SB directly. In these cases, cross the whole MV stent first, then pull back the wire with its tip oriented toward the SB so that it can "jump" naturally into the SB ostium. A gentle torque maneuver helps to feel the lesion and cross it progressively.

****Use a microcatheter** In case of unsuccessful crossing into the SB, the operator can use a microcatheter to help the wire to cross into the SB.

****Redilate the MV stent to widen the MV side cell** After deployment of the MV stent, a short, larger balloon – sized according to the proximal MV diameter – is positioned and inflated with its distal tip at the bifurcation. The operator should exercise care to use short balloons so that the proximal end of this larger balloon is within the MV stent and does not dilate the unstented proximal segment, lest it cause vessel dissection. This technique optimizes the proximal MV stent deployment and, in the process, opens up the stent cells at the bifurcation, thus facilitating wire crossing at the distal struts (similar to the POT technique) (Figure 15.16) [14].

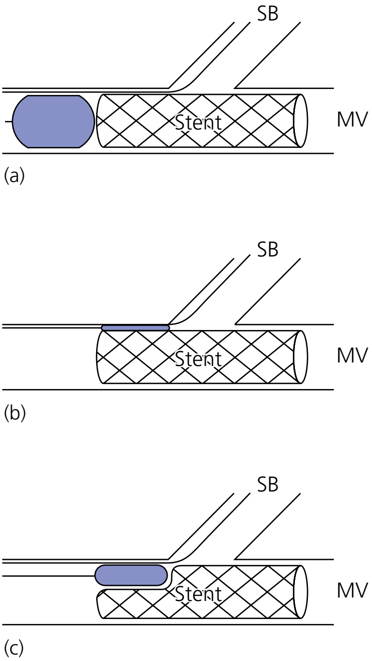


Figure 15.16 (a) Use a small balloon inflation behind the main vessel stent to open a side branch (SB). (b,c) In case of total and symptomatic occlusion of an SB, with failure to pass a wire into the SB lumen from the main vessel (MV) lumen due to dissection, advance a small balloon over the jailed wire (between the stent struts and the vessel wall) and inflate the balloon. Use the smallest balloon available to increase the chance to pass under the stent struts and to avoid major deformation of the MV stent.

****Use a dedicated wire to cross the side cell** In the attempt to cross the MV side cell, apart from the use of an OTW balloon, several other devices may be useful in facilitating the advancement of a wire. The Venture catheter has a deflecting tip that can be directed to the orifice of the SB. Then the Crusade also has similar advantages. Most importantly, before the negotiation of a wire into the SB, the MV stent should be well dilated in order to have wide open cells for SB wiring.

ADVANCE A BALLOON INTO A SIDE BRANCH

In general, the balloon should not be advanced completely through the stent into the SB for inflation because this increases the risk of balloon entrapment. The inflation pressure should also be kept well under the rated burst pressure because balloon rupture within a stent strut can also cause balloon entrapment (Box 15.2).

BOX 15.2 TACTICAL MOVE

Best options for crossing a balloon into the side branch

1. **First Best Option:** Check the wire to be sure it is inside the MV lumen
2. **Second Best:** Advance the tip of a fixed wire balloon across the MV side cell, then inflate the balloon. In select cases, the balloon or stent can be dipped into a lubricant (RotaGlide solution) to facilitate its delivery

Tips and Tricks

****First maneuver when encountering difficulty in advancing a balloon into a SB**
If a balloon cannot pass through the side cell, the position of the wire should be checked to ensure that it is not located underneath the stent strut. A crisscross wire technique can often be used to successfully rewire the SB. First, the SB wire is advanced into the MV, and the MV wire is then inserted into the SB. This method ensures that the SB wire is not trapped under the stent strut. In this technique, the MV wire is pulled back within the MV stent, as far as the SB ostium, before guiding it into the SB. The SB wire is then pulled out proximal to the MV stent and readvanced into the MV. Another possible issue could be wire wrapping, where the two wires become twisted. To address this, pull the MV wire back into the stent, leaving only the soft tip inside. Then, advance the balloon across the struts to the SB, ensuring smooth passage.

****How to advance a balloon into a SB** If it is impossible to advance a balloon across a side strut, an alternative is to cross the stent strut with a balloon on a fixed wire. There is minimal transition between a wire and balloon with a low profile, preserving optimal "pushability" that allows comfortable strut crossing. Furthermore, this method is quick because only one device needs to be inserted. If the balloon fails to advance, repeated, quick, forward and backward movement ("dottering") of the balloon and adjusting the guide position by intubation from time to time may help the balloon to cross.

****Inflate a balloon in the MV as an anchor** If the guide backs out while advancing the wire through the SB, a practical solution is to inflate the MV balloon to serve as an anchor balloon. After gently intubating the guide, a smaller size 1.25-mm or 1.5-mm compliant balloon can usually be advanced into the SB. Inflation should be done carefully to avoid the SB balloon bursting. The MV balloon can be deflated once the SB balloon is advanced to minimize ischemia. The SB can be increased stepwise to its appropriate size.

****Inflate a balloon in the MV to open a side branch** If the balloon cannot pass through the struts of the MV stent to advance into the SB, try pushing the balloon near the SB, with its tip positioned across the stent struts. Inflate the balloon to dilate the stent and create a small opening. Repeat this once or twice and then attempt to push the balloon through. If there is difficulty advancing the balloon, use a compliant monorail 1.5-mm balloon. If this balloon also fails to cross, rewire the SB through a different part of the SB ostium and attempt balloon crossing again. If this still does not work, use a fixed-wire balloon system.

****Lubricate the balloon** The balloon or stent can be dipped into a lubricant (RotaGlide) solution to facilitate its delivery into the SB.

****Small balloon inflation behind the MV stent to open an SB** In case of total and symptomatic occlusion of an SB, with failure to pass a wire into the SB lumen from the MV lumen due to dissection, advance a small balloon over the jailed wire (between the stent struts and the vessel wall) and inflate the balloon. Use the smallest balloon available to increase the chance of passing under the stent struts and to avoid major deformation of the MV stent [16] (Figure 15.16).

****How to withdraw the jailed SB wire** Sometimes the jailed wire is trapped. Forceful withdrawal may result in a broken wire and deeper intubation of the guide, which could result in LM dissection. A practical solution is to use a balloon, advancing it through the jailed wire up the MV stent. Gentle withdrawal of the SB wire will avoid this complication (Figure 15.17).

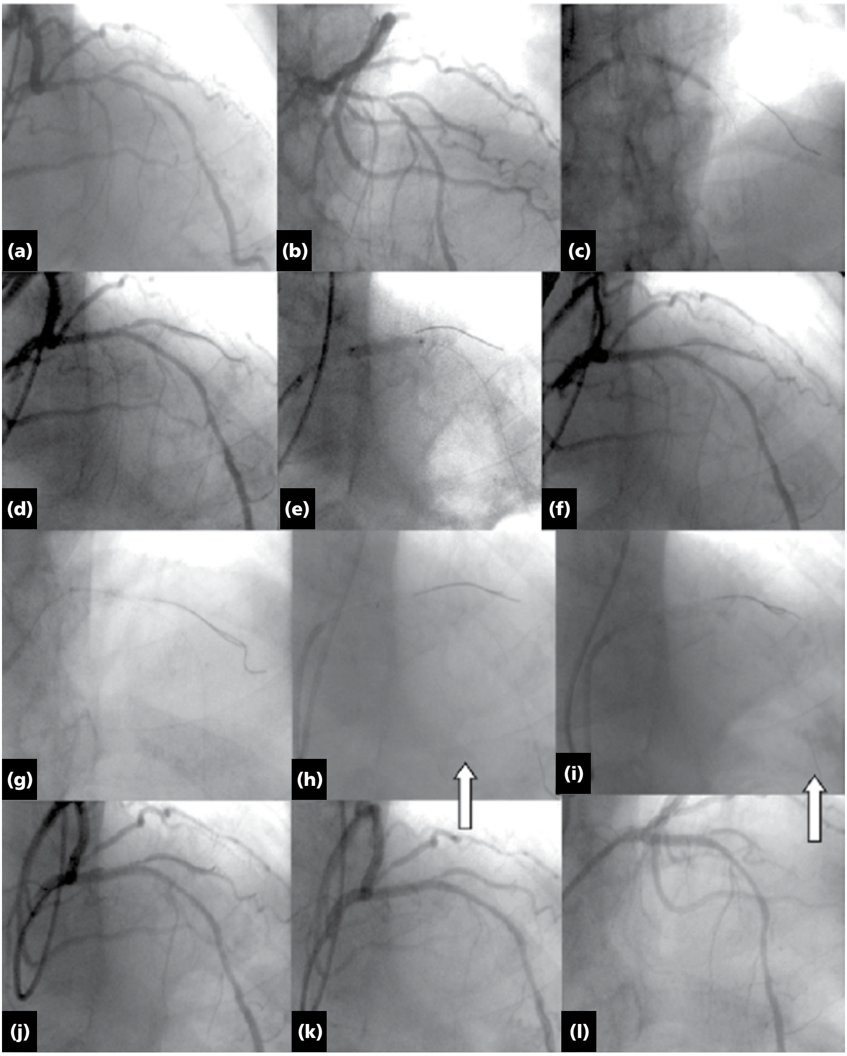


Figure 15.17 Withdrawal of a "jailed" wire. (a,b) Left anterior descending artery with 70% proximal lesion and Medina 0,1,1 bifurcation lesion. (c,d) The main vessel was predilated, and a 3.5 × 20 mm paclitaxel-eluting stent was implanted (e). After diagonal branch rewiring (f), an attempt was made to withdraw the jailed wire (g); however, the wire was blocked and did not move even after very forceful pulling. The insertion of a small balloon close to the stent did not help, and the decision was taken to partially crush the implanted stent. (h) A Maverick 1.5 × 10 mm balloon was inserted as far behind the stent struts as possible and inflated to 15 atm. (i) Next, a Ryujin™ Plus 1.25 × 20 mm balloon was inserted further behind the stent and inflated to 10–15 atm. The wire was freed and slightly pushed, turned, and then pulled outside the vessel (j); there is a haziness behind the stent at the side of the diagonal. Finally, the stent was further dilated with an acceptable result in the diagonal branch (k,l).

In a preventive mode, it is not necessary to advance a wire deeply into the SB. Before performing the crush technique, pull the SB wire back and leave only a short segment across the SB ostium.

SIDE-BRANCH BALLOON INFLATION

After stenting of the MV, if the ostium of an SB shows severe residual stenosis due to carina shift, a small balloon inflation is sufficient to enlarge the ostial SB. If there is severe residual stenosis of the SB ostium, inflation of a relatively larger balloon at lower pressure may help to open further the ostium of the SB.

Tips and Tricks

****Size and pressure for SB inflation after MV stenting** When the proximal MV diameter is <2/3 × (MV + SB) by visual estimation, there are two alternative options: (1) to use intravascular ultrasound to calculate the exact MV diameter or (2) to calculate the MV diameter based on two-branch diameters (see Finet, Murray, and Mitsudo formulae). An exception is when there is a bigger difference in diameter between the MV and SB. In such a situation, the very small balloon diameter in the SB will result in unsatisfactory kissing results, leading to significant distortion of the SB stent.

KISSING BALLOON INFLATION

After deploying the stent in both the MV and SB, optimal results can be achieved by performing KBI with simultaneous dilatation in both branches. However, this technique may not be suitable if the proximal vessel diameter is smaller than that of the involved branches. In such cases, both branches should be dilated more aggressively in sequence using a noncompliant high-pressure balloon, followed by a final low-pressure KBI to limit stent deformation. Avoid using oversized balloons. When both balloons are inflated to 6 atm, proceed with simultaneous inflation and, accordingly, simultaneous deflation.

Main Vessel and Side-Branch Stent Distortion

Stent distortion occurs when, during KBI, the MV balloon diameter is smaller than that of the delivery balloon. The distortion occurs with all stent designs and with all bifurcation techniques. It can be corrected by redilating the MV with an appropriately sized balloon [17]. However, KBI is needed to fully expand the stent in the SB ostium and to repair MV distortion. With SBs angled at 70°, KBI can produce these outcomes. In contrast, with an SB angled at <70°, KBI may not expand the SB stent at the ostium. To expand the stent fully when the branch is angled at >70°, it may be necessary first to postdilate the SB with a balloon that protrudes only a few millimeters into the MV so the balloon is not bent and stays fully straight. After deflation of this balloon, the MV balloon should be dilated with an appropriately sized balloon to repair any distortion [18].

Tips and Tricks

****Diameter of the combined two balloons** As both balloons will be inflated together in the MV proximal to the bifurcation, it is important that they are not oversized. The dilating diameter of the two balloons will be less than the sum of the nominal diameters of both balloons, depending on balloon and vessel compliance and inflation pressure. The selection of the two balloons should follow the Murray formula:

$$D_{\text{mother}}{}^3 = D_{\text{daughter1}}{}^3 + D_{\text{daughter2}}{}^3$$

or the Finet formula:

$$D = 0.67 \times (D1 + D2)$$

where D is the proximal MV diameter and D_1 and D_2 are the diameters of the two branches.

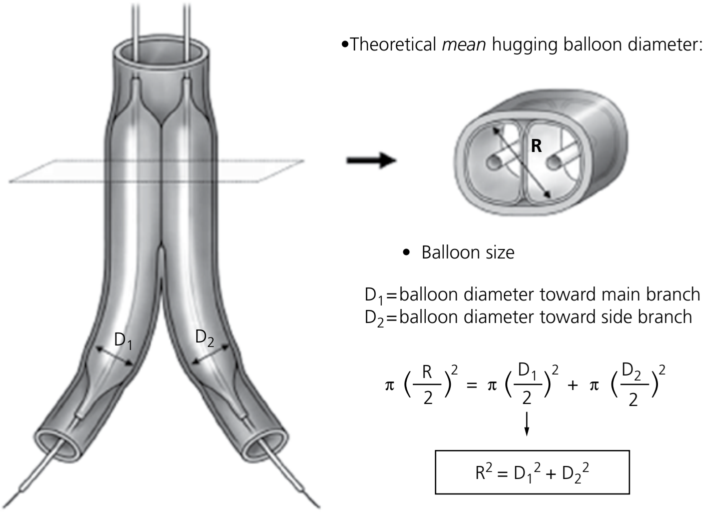

•Theoretical *mean* hugging balloon diameter: R
R
• Balloon size
D_1=balloon diameter toward main branch
D_2=balloon diameter toward side branch
D_1
D_2
$\pi\left(\frac{R}{2}\right)^2 = \pi\left(\frac{D_1}{2}\right)^2 + \pi\left(\frac{D_2}{2}\right)^2$
$\boxed{R^2 = D_1^2 + D_2^2}$

Figure 15.18 Principle of the kissing balloon "formula" (Mitsudo's proposal). Source: Courtesy of Dr Kazuaki Mitsudo.

These formulas are based on structure–function scaling laws of the branching vascular tree.

There is an alternative, the Mitsudo formula, which is based on flow conservation law and estimates the theoretical mean hugging balloon diameter at the "kissing balloon segment" (i.e. it is based on balloon diameters rather than fractal geometry of the vascular bifurcation):

$$R^2 = D_1^2 + D_2^2$$

where R = theoretical mean hugging balloon diameter, D_1 = MV balloon diameter, and D_2 = SB balloon diameter [19] (Figure 15.18).

****Perfect kissing balloon inflation** What is of paramount importance is to perform a high-pressure balloon inflation in the SB in order to be sure to fully expand the stent at the ostium of the SB. KBI is then performed at medium pressure, usually 15 atm (when the two balloons are inflated together), to avoid any proximal dissection. Deflating the balloons simultaneously may help to prevent any further distortion of the stent struts, thus avoiding incomplete apposition [18].

The inflation pressure for KBI is recommended to be no more than 16 atm. The overlapping length of the two balloons in the proximal portion beyond the carinal level is as short as possible to avoid the twisting of the two balloons.

ACTION POINTS

For PCI of a bifurcation lesion, the appropriate selection of devices is crucial. Careful consideration of the guide catheter with a sufficient inner lumen is essential before the procedure. A 6-Fr guide is adequate for most procedures, except when using two balloons or stents with diameters >3.0 mm. A 7-Fr guide can be used for all procedures, including rotational atherectomy with up to a 1.75-mm burr. The wire used for "jailed" SB should be nonhydrophilic, as a hydrophilic wire is not ideal for SB rewiring. If the

(*Continued*)

provisional SB stenting technique is employed, intravascular ultrasound (IVUS) is valuable for identifying the causes of a narrowed SB ostium (e.g. carina or plaque shifts). When the SB ostium is narrowed due to carina shift, a small balloon is sufficient to enlarge it. However, if the compromise is due to plaque shift, a larger balloon is required. In such cases, it is essential to avoid distal SB dissection. When using two-stent techniques, sequential inflations with a noncompliant balloon for the SB, followed by KBI at higher pressures, are critical for optimal results.

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CHAPTER 16

Complications

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

During percutaneous coronary interventions (PCIs), there are three possible major mechanical complications: acute or threatened closure, perforation, and no-reflow. These events can cause prolonged ischemia, hemodynamic instability, collapse, and death. The causes of acute or threatened closure include dissection, thrombotic formation, air embolism, extraluminal compression and antegrade aortic dissection. Other complications include no-reflow, retrograde aortic dissection, emboli to the central nervous system, and reaction to contrast agents. The incidence of complications depends on the operator’s skill, the technology available, and patient selection. Rigorous preventive measures preempt the appearance of complications. Operator experience, although it may be difficult to define, is extremely important in minimizing and treating the complications of PCI. With the use of current low-profile balloons and high-torquable wires, most patients with “simple” stenoses will have good results, even in the hands of relatively inexperienced operators. However, in patients with complex anatomy or when simple cases become complicated, experienced operators (who perform at least 75–150 cases per year) are likely to have superior outcomes [1]. With better equipment, stronger antiplatelet medications, and higher levels of operator experience, the incidence of complications from stenting is very low: less than 0.4% in mortality, abrupt closure, or emergent coronary artery bypass graft (CABG) surgery. This is why the level of the operator’s experience should dictate case selection in patients with multiple risk factors and complex anatomy. Prevention is always the priority because it is better to stay out of trouble than to get out of trouble.

CONTRAST-INDUCED ACUTE KIDNEY INJURY

Contrast-induced acute kidney injury (CI-AKI) after PCI is defined as an increase of creatinine level of a rise in Cr > 0.3 mg/dL or > 50% from baseline. The risk factors for CI-AKI are listed in Table 16.1 [1].

Hydration

The usual protocols administer a total of at least 1 L of isotonic saline beginning at least 3 h before and continuing at least 6–8 h after the procedure. Initial infusion rates of 100–150 mL/h are recommended, with adjustment post procedure as clinically indicated. Appropriate caution should be applied to the patient with known left ventricular dysfunction or heart failure.

Medications

Pre-procedural management of patients at risk for CI-AKI requires a review of the patient's medications and withholding, as clinically appropriate, potentially nephrotoxic drugs, including aminoglycoside antibiotics, anti-rejection medications, and nonsteroidal anti-inflammatory drugs (NSAIDs) or antidiabetic drugs (e.g. metformin). Although optimizing volume status is essential, the decision to interrupt diuretic therapy must be individualized. Angiotensin-converting enzyme inhibitor therapy may continue, but neither initiating nor changing the dose should be considered until the patient is safely past the risk period for CI-AKI (the creatinine will increase to its peak 48 h after the procedure).

Lower Amount of Contrast

Intuitively, the less contrast administered, the lower the risk for CIN. However, there are no studies that prospectively evaluate this hypothesis. Retrospective analyses have suggested that a total dose of <30 mL for diagnostic studies and <100 mL for interventional procedures lessens the risk for CIN [1]. The recommendations for prevention of CIN are listed in Table 16.2.

Stents should be used liberally to shorten procedure time and achieve stable acute results. Intravascular ultrasound (IVUS) can be used to monitor the procedure. A variety of adjuncts, such as a wire with interval markers and digital road mapping, can help in positioning stents or balloons. All these efforts help to minimize the amount of contrast agent used during the procedure. There is, of course, no risk of nephrotoxicity in patients already on dialysis, although volume overload should not be overlooked [1].

Table 16.1 Pre-procedural clinical risk factors for CIN

Modifiable risk factors	Non-modifiable risk factors
Contrast volume	Diabetes
Hydration status	Chronic kidney disease
Concomitant nephrotoxic agents	Shock/hypotension
Recent contrast administrations	Advanced age (>75 years)
Advanced congestive heart failure	

Table 16.2 **Recommendations for prevention of CIN**

1. **Identify risk**
   a. Low risk – eGFR >60 mL/1.73 m^2
      i. Optimize hydration status
   b. High risk – eGFR <60 mL/1.73 m^2
      i. Schedule outpatient for early arrival or delay procedure time to allow time to accomplish hydration
      ii. Consider the following recommendations (2–5)
2. **Manage medications**
   a. Withhold, if clinically appropriate, potentially nephrotoxic drugs including aminoglycoside antibiotics, antirejection medications, and NSAIDs
   b. Administer *N*-acetyl cysteine (equivocal data, see text)
      i. 600 mg administered orally every 12 h × four doses beginning prior to contrast
3. **Manage intravascular volume (avoid dehydration)**
   a. Administer a total of at least 1 L of isotonic (normal) saline beginning at least 3 h before and continuing at least 6–8 h after the procedure
      i. Initial infusion rate 100–150 mL/h adjusted post procedure as clinically indicated
   b. Sodium bicarbonate (limited data, see text)
      i. 154 mEq/L @ 3 mL/kg/h starting 1 h before contrast
      ii. 154 mEq/L @ 1 mL/kg/h for 6 h following contrast
4. **Radiographic contrast media**
   a. Minimize volume
   b. Low- or iso-osmolar contrast agents (ongoing data, see text)
5. **Postprocedure: discharge/follow-up**
   a. Obtain follow-up serum creatinine 48 h post procedure
   b. Consider withholding appropriate medications until renal function returns to normal, i.e. metformin, NSAID

Tips and Tricks

****How to do PCI with 20 mL of contrast?** At the beginning of the PCI, the patient had two wires: one through the lesion and one in a branch nearby. Throughout the procedure, the positioning of the balloon and the stent was determined by referring to the bifurcation of the wires. Instead of regular angiography, selective angiography with 1.5 mL of contrast media was performed by injecting the contrast through the tip of a transport catheter that was inserted into the proximal portion of the artery along the marker wire. IVUS was repeatedly performed to confirm the result of each intervention. Because of these efforts to minimize the dose of contrast media, the procedure was completed with the use of 15 mL of contrast media [1]. Options to reduce the contrast load are listed in Box 16.1.

BOX 16.1 TACTICAL MOVE

Best Options in Minimizing Contrast During PCI

1. $ FIRST Best option: Graduated wire
2. $ SECOND Best option: Perform selective angiography with 1.5 mL of contrast from the tip of a small catheter placed into the index artery
3. $ $ THIRD Best option: IVUS only, no angiogram

CONTRAST ALLERGY

Prevention

The key to preventing contrast reactions is to identify the patients at greatest risk and use prophylactic measures to reduce their risk. Patients with previous contrast reactions or a history of atopy or asthma are at increased risk. It is common to use lower-osmolality contrast agents, e.g. iodixanol (Visipaque™, Nycomed, Oslo, Norway), in these patients. Many pretreatment protocols use the combination of corticosteroids, histamine-1 (H_1)-receptor antagonists, and (H_2)-receptor antagonists. Usually, prednisone 50 mg is given at 13, 7, and 1 h prior to the procedure. If steroids are not given prior to the procedure, 100 mg of hydrocortisone sodium succinate should be administered intravenously at the time of the procedure.

Mild reactions, including itching, rash, or urticaria, are usually self-limiting and require no further intervention beyond prompt recognition and careful monitoring for possible progression. A reaction such as bronchospasm requires aggressive treatment with epinephrine 0.1–0.3 mL administered intramuscularly (IM), 1:1000 dilution, at first. The IM injection has a problem with drug diffusion if the patient has hypotension and subsequent vasoconstriction. In the event of a severe reaction (Table 16.3), such as severe bronchospasm, laryngeal edema, or cardiopulmonary arrest, intravenous epinephrine may be given in a diluted form (1:10 000) at a dose of 1–3 mL. Infusion of epinephrine titrated to effect is better than reliance on a single intravenous bolus dose. Supplemental oxygen and ample intravenous fluid infusion can mitigate the effects of hypoxia and hypotension, respectively [2].

THREATENED OR ACUTE CLOSURE

Threatened closure is defined as narrowing of the artery <50% during PCI with evidence of active ischemia (chest pain or electrocardiographic [ECG] changes). The many causes of acute closure include dissection, coronary spasm, air embolism, and distal embolization of plaque and/or thrombus. However, the most feared cause is dissection.

Dissection

Dissection is defined as the two lumens separated by a large tissue flap. Dissection is caused by excessive iatrogenic plaque fracturing from balloon inflation or device manipulation with subsequent separation of the layers of the vessel wall.

During a diagnostic or interventional procedure, the tip of a catheter or guide can cause dissection at the ostium of a left main (LM) or right coronary artery (RCA). The dissection can propagate in an antegrade or retrograde direction.

Antegrade propagating dissection may possibly stop at a previously stented area due to compression of the three layers of the arterial wall by the stent or often at the bifurcation with a big side branch. If dissection occurs in the proximal and mid-segment of the left circumflex artery (LCX) that is encased inside the atrioventricular (AV) groove, the dissection is usually not propagated very far distally. However, because the dissection is confined in a tight space (narrow corridor), the luminal encroachment by the dissection is more severe (Figure 16.1).

Table 16.3 Early Signs of Shock

Sinus tachycardia
Narrow pulse pressure
Slender aortic pressure curve

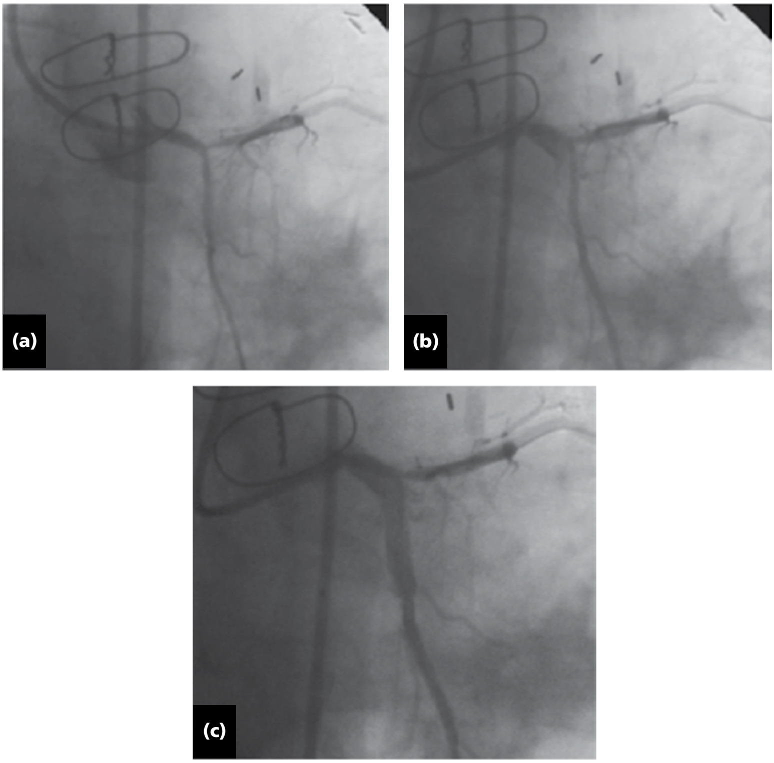


Figure 16.1 Anatomy of a left main (LM) dissection by a guide. (a) An injection opacified the LM and the left circumflex artery (LCX). (b) There was a lifting of the entry site that propagated distally. (c). The dissecting plane advanced forward; however, it was stopped by the branching of an obtuse marginal.

Besides antegrade dissections from the LM, the RCA, the left internal mammary artery (LIMA), and the saphenous vein graft (SVG), a dissection can propagate distally in a retrograde fashion. The LIMA can be easily dissected at the time of performing selective angiography or guide cannulation. Local dissection of an SVG at the proximal (especially SVG to RCA) or ostial segment, which is caused by guide manipulation, looks benign but can progress rapidly to acute occlusion.

Table 16.4 Grading of Coronary Artery Dissection

Type A: Minor radiolucency within the coronary lumen with minimal or no persistence after dye clearance

Type B: Parallel track or double lumen separated by a radiolucent area during contrast injection with minimal or no persistence after dye clearance

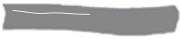
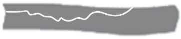
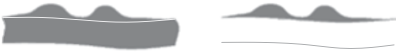
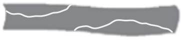
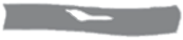
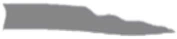
Type C: Extraluminal cap with persistence of contrast after dye clearance

Type D: Spiral-shaped filling defects

Type E: New persistent intraluminal filling defects

Type F: Dissection leading to total occlusion without distal antegrade flow

The transition between a therapeutic fracture (balloon angioplasty) and a threatening dissection is ill-defined; the National Heart, Lung, and Blood Institute (NHLBI) classification of dissection is shown in Table 16.4 [3] (Figure 16.2).

Dissection type	Description	Angiographic appearance
A	Minor radiolucencies within the coronary lumen during contrast injection with minimal or no persistence after dye clearance.	
B	Parallel tracts or double lumen separated by a radiolucent area during contrast injection with minimal or no persistence after dye clearance.	
C	Extraluminal cap with persistence of contrast after dye clearance from the coronary lumen.	
D	Spiral luminal filling defect.	
E+	New persistent filling defects.	
F+	Those non-A-E types that lead to impaired flow or total occlusion.	

+ May represent thrombus.

Figure 16.2 Type A dissections represent minor radiolucent areas within the coronary lumen during contrast injection with little or no persistence of contrast after the dye has cleared. Type B dissections are parallel tracts or a double lumen separated by a radiolucent area during contrast injection, with minimal or no persistence after dye clearance. Type C dissections appear as contrast outside the coronary lumen ("extraluminal cap") with persistence of contrast after dye has cleared from the lumen. Type D dissections represent spiral ("barber shop pole") luminal filling defects, frequently with excessive contrast staining of the dissected false lumen. Type E dissections appear as new, persistent filling defects within the coronary lumen. Type F dissections represent those that lead to total occlusion of the coronary lumen without distal antegrade flow. In rare cases, a coronary artery dissection may propagate retrogradely and involve the ascending aorta. Illustrated by Quoc Nguyen.

GAME PLAN

The two factors defining prognosis after a dissection are (1) the length of the compromised vessel and (2) the integrity of the antegrade flow. Minor dissection that does not compromise the coronary flow does not need treatment. If the vessel diameter is <2.5 mm, the best strategy is to repeat prolonged low-pressure balloon inflations with a slightly oversized balloon or longer balloon. Dissections that are long (resulting in > 50% residual stenosis) and impair flow are considered severe and should be stented promptly, especially if the vessel diameter is >2.5 mm.

Securing and maintaining wire access across the occluded artery is the single most important consideration in managing acute abrupt vessel closure. In the case of spiral dissection, stenting the distal end to stop further propagation of the dissection and the entry site stops the source of dissection. However, some dissections cannot be stented (2–3%) because of severe proximal tortuosity, small size of the vessel, etc. The majority of dissections do not result in acute ischemic complications and heal with time without future stenosis. Precautionary measures and tactics for prompt reversal of acute closure are listed in Table 16.5.

Table 16.5 **Precautionary Measures and Tactics for Prompt Reversal of Acute Closure**

1. Maintain wire across lesion
2. Prompt balloon reinflation
3. Prompt placement of stent to stop dissection
4. Ready access to contralateral artery and vein with 5-Fr sheaths in case IABP hemodynamic support is needed (unless the artery is stented promptly)
5. Prior to PCI, perform a lower abdominal aortogram to identify patients who may not tolerate IABP or left ventricular assist device (LVAD) placement
6. IABP or LVAD may be inserted prophylactically in selected patients or on standby for immediate insertion in case of hypotension or ischemic complication

Table 16.6 **Differential diagnoses of dissection**

Causes	Corrective techniques
1. Streaming of contrast	Advance the guide deeper into the ostium with more forceful and steady injection of contrast
2. Deep guide intubation	Pull the guide back a little
3. Stiff wire straightening the vessel	Withdraw the wire with the flexible tip proximal to the new lesion
4. Overlapping of radio-opaque wire	Withdraw the tip proximal to the new lesion
5. A thin branch running parallel to the index artery	Change the angle of projection of the camera

Tips and Tricks

****Distinguishing dissection from its look-alikes** An intraluminal flap or an extraluminal linear or spiral extravasation of contrast media would suggest dissection. An oval-shaped intraluminal lucency with smooth contour, or an area with haziness, or a flat, rounded cut-off would suggest a thrombus. Spasm would have a more tapering end. On IVUS, spasm is seen as narrowing without plaque. Other possible causes of pseudo-dissection are listed in Table 16.6.

ACTION PLAN

Management of the locally dissected lesion is prompt local stenting, whereas management of the ostial dissection that propagates distally consists of stenting of the ostial LM or RCA first, then the distal dissected segment next. In any situation, the wire must be maintained across the dissection.

If there is only minor dissection, there is no need for treatment. In the case of edge dissection following stent deployment, it is not imperative to cover all the edge dissections that are considered minor, with a residual lumen on IVUS >50%, or not in a strategic location (not in the LM or at the ostium of a major branch) [1].

Tips and Tricks

***Preventing dissection** In order to prevent dissection, usually the patient would have low-pressure 6–8 atm balloon predilation. However, in cases of a lesion with unexpectedly heavy calcification, due to inadequate balloon predilation, some stents cannot be fully expanded. The key point is that, for predilation, a non-compliant, small balloon (e.g. 2.5-mm diameter) needs to be fully inflated without a waist at its middle. Other strategies include minimal manipulation of any devices prior to stent placement to limit the occurrence of dissection at the ostium or at the segment proximal to the lesion. Then prompt stenting of the dissecting segment would prevent further propagation of the dissecting plane.

***Prevention of dissection during LIMA cannulation** This kind of dissection can be prevented by non-selective cannulation: insert the wire first, advance a non-inflated balloon through the ostial LIMA, and adjust the guide to a coaxial position with the balloon and wire as support devices. Use of a buddy wire parking in the subclavian artery to prevent deep engagement of the guide into the diseased ostium or use of a smaller guide (5 Fr or 4 Fr) are other options in preventing ostial dissection.

****Re-crossing the dissected segment** Once the wire position is lost, try to re-cross the lesion with a very soft wire rather than a stiff wire. The post-angioplasty angiogram should be reviewed carefully. Look for the plane of dissection and the most likely location of entry to the true lumen by many different orthogonal views. The tip of the wire is then positioned at that location and manipulated to enter the true lumen.

Usually, by computational fluid dynamics study, the cholesterol plaque is formed on the myocardial side of the artery due to slow flow at the inner curve or myocardial side. The dissecting plane is therefore between the plaque and the medial muscular layer. To advance the wire into the true lumen, the tip of the wire should point toward the outer curve or the pericardial aspect of the artery.

If there is a problem with re-crossing the segment or entry in the false lumen, an IVUS study should be done and the artery re-crossed by a second wire parallel to the IVUS so that it can be advanced into the true lumen under IVUS guidance.

****Re-entry into the true lumen in a stented area** When a wire attempts to cross a stent, it may advance outside the stent, behind the stent struts. In this situation, the balloon could be advanced along the wire behind the stent and inflated in the false path. A dissection could occur and be propagated in a retrograde or antegrade fashion. In this situation, a new wire must enter the true lumen in order to secure persistent true lumen access. In any situation, do not remove the wire across the lesion unless there is strong evidence that it is in the false lumen. A careful review of the diagnostic angiography would show the origin of the dissection (local or ostial) and whether or not the wire is in the true lumen. A summary of the management of dissection is shown in Table 16.7.

****Early detection of retrograde aortic dissection** When there is suspicion of retrograde dissection, pull the guide back. An injection of contrast in the coronary sinus would help to confirm the presence of retrograde aortic involvement.

Table 16.7 Management of dissection according to site of origin

Site of origin	Wire management
Ostium	Keep the wire in place Stent the ostium first
Local (non-ostial)	Keep the wire in place Stent the local dissecting area
Local, wire in false lumen	Keep the wire in place *Insert second wire in true lumen *Remove first wire only after firm evidence that it is in a false lumen *Stent the narrowing area of the true lumen

Left Main Dissection

LM dissection is the forerunner to catastrophic vessel closure. It can be precipitated by manipulation of interventional hardware in the LM ostium or during intervention of the ostial lesion of the LAD. Sharp angulation at the LM–LAD junction appears to be a risk factor for LM dissection when an inflated balloon for an ostial LAD lesion partially covers the LM [1]. The usual LM injury management is CABG. However, it is necessary to keep the patient stable while waiting for emergency surgery. Unprotected LM PCI is not a common procedure for most operators in the United States. Even so, to save the life of the patient, the acutely occluded LM must be opened as a bailout emergency procedure, similar to pericardiocentesis in tamponade. The strategy is to stent the LM even before inserting the temporary pacemaker and the mechanical support device (Impella, Abiomed, Inc., a subsidiary of Johnson & Johnson MedTech, Danvers, MA, USA). To ensure complete coverage of the LM ostium, position the stent with 1–2 mm of its proximal end protruding into the aorta. Confirm optimal placement using IVUS and multiple angiographic views, especially a shallow left anterior oblique (LAO) cranial projection. The whole emergency procedure should be finished in a matter of minutes to reverse the process of hemodynamic collapse, shock, or impending death. Once the patient is stabilized, the decision about CABG can then be entertained (see Figure 16.1). The technique of LM stenting is discussed in detail in Chapter 10.

Tips and Tricks

****Can the LM dissection be missed by a small guide?** On many occasions there is a clear discrepancy between the dramatic clinical presentation (severe chest pain, hypotension, ST–T change) and the paucity of the coronary artery findings. In these situations, additional orthogonal views need to be taken to confirm the non-involvement of the coronary system or the presence of aortic dissection or LM dissection masquerading as acute myocardial infarction (AMI). In a diagnostic angiography, a small guide could cross the severe ostial lesion of the LM without causing ventricularization of pressure, so the ostial lesion or dissection of the LM could be missed. In situations where there is strong suspicion of LM dissection by ST elevation in the anterior leads, a repeat angiogram should be done with a larger guide to detect the ostial lesion caused by dissection. Another way to detect the LM dissection is to pull the guide barely outside the LM ostium and inject the contrast to opacify the whole LM segment [4].

Retrograde Aortic Dissection

Retrograde aortic dissection secondary to coronary dissection usually happens after inflation of the proximal RCA (more common) or the LAD (Figure 16.3). Even though it is rare, it must be positively ruled out when there is unexplained chest pain or hypotension or persistent opacity by contrast at the aortic root after angioplasty or stenting of any ostial or proximal lesion. If it is detected early, prompt corrective measures include prompt stenting of the ostial lesion,

CRITICAL THINKING

The pathophysiology of iatrogenic aortocoronary dissection is different from that of spontaneous aortic dissection, and this may explain the different management strategies and prognoses of these two entities. In spontaneous aortic dissection of the ascending aorta, the significant degeneration of the media facilitates the propagation of dissection with extensive arterial damage that warrants urgent surgical therapy [5]. On the other hand, there is no evidence to indicate that degeneration of the medial layer of the aorta is a prerequisite for the development of catheter-induced aortocoronary dissection. Moreover, the aortic supravalvular stria, rich in collagen fibers, may limit progression of the iatrogenic dissection beyond the sinotubular junction [6].

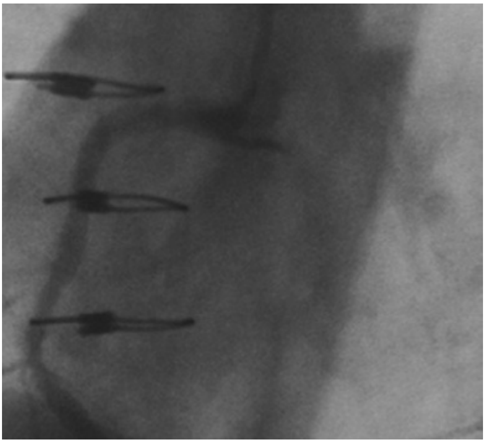


Figure 16.3 After inflation of the proximal RCA, there was persistent contrast staining at the ostium of the RCA on the aortic wall area.

CRITICAL THINKING

In Patients with Retrograde Ascending Aortic Dissection, When to Send for Surgery and When to Keep Patients for Medical Treatment?

An "extensive" aortic dissection has arbitrarily been defined in the largest reported series to date as one that extends >40 mm up the aorta from the coronary cusp [5]. Applying this definition, seven of eight extensive aortic dissections reported in the literature to date have been surgically managed, with two deaths. One patient with an extensive dissection was deemed unsuitable for surgery (due to the extent of dissection and history of prior cardiac surgery) and was successfully managed with a conservative strategy. Of the 13 patients with dissection limited to <40 mm of the ascending aorta, 12 have been medically managed, with no deaths. Surgery was required in one patient who had suffered a limited dissection, but in this case the procedure was indicated primarily for emergent coronary bypass and not aortic repair [5]. Stents at the site of the presumed entry site for aortic dissection in the culprit coronary vessel were successfully deployed. All patients survived, and only two patients required subsequent surgery (in one case due to the development of hemopericardium, in the other due to the very extensive nature of the dissection, which had progressed to the aortic bifurcation) [5]. The lesson is, if the patient has extensive retrograde aortic dissection of >40 mm, surgery is suggested. If the dissection is <40 mm, medical therapy is suggested.

which is the entry site, to seal off the dissection. Surgical consultation is needed when there is significant aortic regurgitation, involvement of the supra-aortic vessels, and progression of the index dissection. If none of these problems is present, watchful waiting is the best approach [5]. A follow-up CT scan of the chest may identify the medically stabilized patient who needs no further treatment or the complicated patient who may need surgery [5].

How You Can Make a Difference

In general, a large majority of iatrogenic dissections are limited to the coronary sinus, whereas a large minority progress either to the ascending aorta or retrogradely, causing aortic regurgitation and/or hemopericardium. In cases with limited dissection, many patients can be treated with ostial stenting and a large minority can be managed conservatively. Among rapidly progressing dissections, stenting was successful, even in cases of hemopericardium managed percutaneously with pericardiocentesis and stenting. The worst prognosis was observed in patients with rapid progression of dissections who were managed conservatively and in those with concomitant myocardial infarction who required surgery. Hence, every effort should be made to prevent rapid progression of the dissection. This can be achieved by immediate and appropriate stenting to seal the entry site of dissection and to stop blood flow into the false lumen. Moreover, even if ostial stenting fails to halt the progression of dissection, it will not compromise the chances of surgical success [6].

ACTION POINTS

Precautionary measures that can minimize the occurrence of iatrogenic dissection include the following:

1. Avoid deep engagement of the guide
2. Pull the guide back a little while any interventional or diagnostic device is withdrawn from the artery. Continuously monitor the tip of the guide so it is not sucked in
3. Do not keep the guide too long in the deep engagement position inside the LM
4. Check the pressure waveform before every coronary injection. If a ventricularized pressure waveform is observed, the guide should be pulled out or torqued slightly until a normal arterial pressure waveform is observed
5. Prompt recognition of dissection to prevent further retrograde and antegrade extension. Always check the proximal segment or ostium of the instrumented artery before finishing a diagnostic or interventional case
6. Prompt stenting to seal the dissection
7. In the presence of hemodynamic instability, prepare/insert a left ventricular assist device (e.g. Impella) and call the surgeon

ACUTE THROMBOTIC CLOSURE

Even when the technical aspect of a PCI is almost flawless, the possibility of acute closure by uncontrolled platelet aggregation and new occlusive thrombotic formation still exists, not infrequently with superimposed vascular spasm. A thrombus is recognized as a progressively enlarging or mobile intraluminal lucency surrounded by contrast. Its incidence is low in stable angina patients. However, in patients with acute coronary syndrome, lesions with thrombus, long and diffuse lesions, or degenerated vein grafts, the probability of an acute occlusion due to thrombotic formation or distal embolization is high [7]. After stenting, acute closure due to subacute thrombosis happens if there is incomplete apposition of stent struts against the vessel wall and unrecognized mechanical obstruction proximal or distal to the stent (Figure 16.4a–b). To prevent thrombotic formation, in the case of a short procedure with minimal injury to the endothelium, besides anticoagulation with heparin or bivalirudin, prior treatment with oral antiplatelet drugs such as aspirin plus clopidogrel is sufficiently effective. A bolus of 300 mg of clopidogrel should be given for at least 24 h prior or 600 mg for at least 6 h prior to the procedure. In the case of extensive injury to the endothelium by interventional hardware, the prospect of recurrent thrombosis could also be preempted by prior infusion of glycoprotein IIb/IIIa inhibitors [7]. This is why minimal manipulation of the artery lumen prior to stent placement limits the depth and extent of vessel wall injury at the segment proximal to or around the lesion.

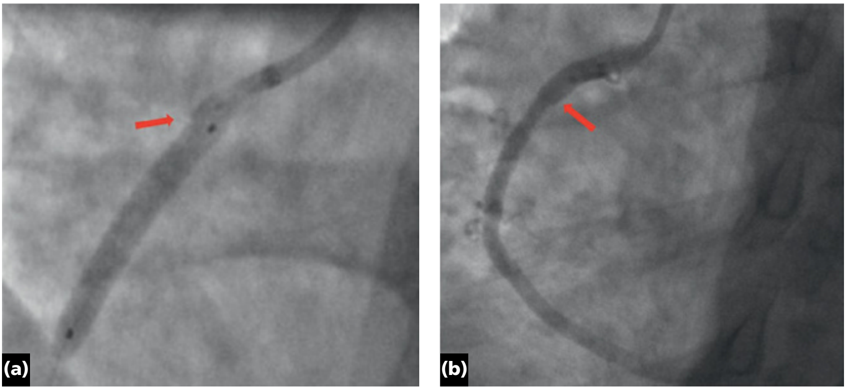


Figure 16.4 (a) A patient underwent stenting of the mid-segment of a right coronary artery (RCA). Because the mid-segment of the RCA was much smaller than the proximal segment, the struts at the proximal end of the stent did not appose well against the arterial wall (red arrow). (b) Even there was normal flow at the final angiogram, the RCA later became acutely occluded.

Causes of Acute Occlusion after Stenting

If stenting is the best strategy for prevention or treatment of occlusion, how can occlusion happen after stenting [7]? The usual causes of occlusion after balloon angioplasty and stenting are distal dissection and thrombus. However, after stenting, protrusion of tissue or malapposed struts may compromise the lumen and cause thrombotic formation. The common denominator of these occlusions is a compromised distal blood flow promoting thrombotic formation. Perfect thrombolysis in myocardial infarction (TIMI) 3 flow after stenting is the best way to prevent any significant and severe thrombotic complications [7].

Tips and Tricks

Dissolution or removal of occlusive intracoronary thrombus During an interventional procedure, if there is mild haziness at the lesion site or at the proximal segments, this is the early sign of thrombotic formation. At that moment the main goal is to have TIMI 3 flow, because perfect flow is the best prevention against thrombotic formation and against high shear stress, which activates platelet aggregation. The best maneuver ranking of each method in removing a thrombus is listed in Box 16.2.

BOX 16.2 TACTICAL MOVE

Best Options for Removing a Thrombus

1. **FIRST Best Maneuver is to check the integrity of the artery and its perfect flow. Best Maneuver – rule out dissection:** Occult dissection at the lesion site or in its proximal segment has to be ruled out by IVUS. If there is dissection that impedes the flow, prompt stenting is best
2. **SECOND Best Maneuver** When there is new haziness (small thrombi) occluding the proximal or mid-segment of an artery, some operators would forcefully inject contrast or normal saline. The goal is to dislodge small and soft thrombi
3. **$$ ⧗ THIRD Best Maneuver:** Use the balloon to squeeze the thrombus and spread it to the wall
4. **$$ ⧗⧗ 💧💧 FOURTH Best Maneuver:** Removal of thrombus with thrombectomy catheter or devices

While the thrombus is being taken care of, the usual emergency measures have to be taken to keep a decent blood pressure with IABP, temporary pacemaker, intravenous fluid, etc. Activated clotting time (ACT) should be >250 s.

STENT FRACTURE

Restenosis associated with stent fracture is thought to occur due to drug maldistribution (for drug-eluting stents), strut fracture, and local mechanical irritation that triggers neointimal hyperplasia. Exposure of a free metal strut into the lumen can trigger platelet activation, resulting in thrombosis. Thrombosis and in-stent restenosis (ISR) may present as a spectrum that includes stable and unstable angina, ST elevation myocardial infarction, and potentially sudden cardiac death. Focal stenosis is related to stent fracture, with the majority of stent fractures occurring in the middle portion of the stent (Figure 16.5).

Asymptomatic patients without restenosis can be followed closely without intervention; however, extension of dual antiplatelet therapy beyond 1 year might be considered. If symptoms are present, further intervention should be sought. The stent-in-stent technique is commonly employed when symptoms are present and the fracture is associated with restenosis [9].

NO-REFLOW

No-reflow is defined as stagnant contrast agent in the distal vasculature without apparent proximal obstruction. The incidence is 2% with plain balloon angioplasty (percutaneous transluminal coronary angioplasty [PTCA]), 7% in patients undergoing rotational atherectomy, 12% for primary angioplasty, and much higher at 42% for PCI of degenerated SVG. The cause is principally embolization of atheromatous material (gruel), aggravated by microembolization of platelet-rich thrombi that release vasoactive agents (e.g. serotonin), leading to intense arteriolar vasospasm in the distal vasculature [10]. The differential diagnosis of an apparent no-reflow phenomenon is dissection or acute thrombotic formation in the proximal or distal segment, which is not always well appreciated by conventional angiography.

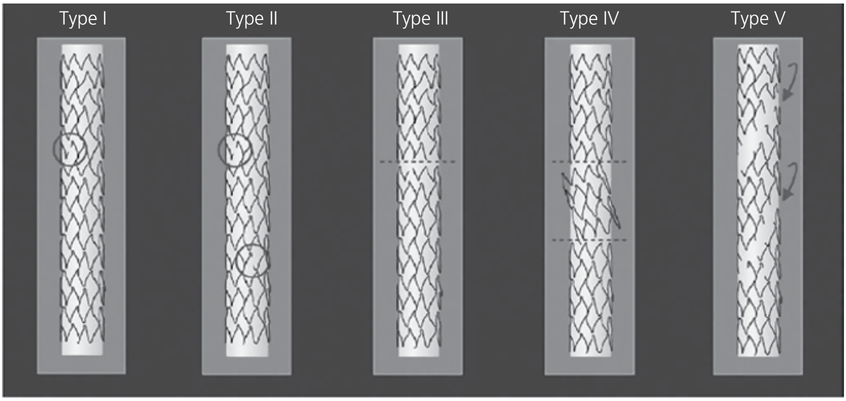


Figure 16.5 Stent fractures. Source: Reproduced with permission from [8] / John Wiley & Sons.

IMPROVISED EQUIPMENT

An over-the-wire (OTW) balloon, microcatheter, or aspiration catheter can help to find the cause of no-reflow. The catheter should be inserted through the wire and advanced to the distal segment of the no-flow area. Then the wire is removed. The pressure gradient between the tip of the catheter and guide is measured, and contrast injection through the end-hole will help to make the distinction between no-reflow and proximal obstructive lesions. Subsequent injection of 3–5 mL of contrast agent with slow withdrawal of the catheter into the guide is useful to reveal any proximal disease, however hemodynamically insignificant. Off-label use of a monorail balloon with multiple small punctures in the balloon will allow for distal contrast injection through the balloon lumen provided the contrast is significantly diluted.

Advantages and Limitations

The most important limitation of the improvised equipment is the inability to maintain distal wire position, particularly in the presence of a dissection. The limitation of a large-size thrombectomy catheter is the potential to worsen dissection or catch on stent struts. IVUS offers an option to determine the presence of a dissection or thrombus at the flow arrest site. However, IVUS is unable to determine the distal runoff of the vessel and the presence or absence of a very distal thrombus [9]. In this situation, advance a second wire to the distal segment to maintain vascular access.

DEDICATED EQUIPMENT

E

With dedicated equipment such as the Twin-Pass® catheter (Teleflex Medical, Wayne, PA, USA), a diagnostic approach can be performed in a safer and better environment. The Twin-Pass dual-access catheter is a hydrophilically coated, dual-lumen catheter designed for use in the arterial vasculature. The catheter provides support for 0.014-inch × 0.36-mm wires during interventional procedures, and the dual-lumen design allows for the delivery of a second wire into the distal vasculature while leaving the initial wire in place. The distal exit port is from a 20-cm-long monorail wire lumen, while the proximal exit port emanates from a lumen extending back to the hub in an "OTW" configuration [10].

The Twin-Pass catheter comes with a stiffening mandrel to provide support and pushability during catheter insertion. It is compatible with a minimum guide catheter internal diameter of 0.058 inch × 1.47 mm. The Twin-Pass catheter has a radio-opaque marker band located approximately 1 mm proximal to the distal tip and a second radio-opaque marker band located at the through-lumen exit port 10 mm proximal to the distal tip. The crossing profile of the distal tip is <1.9 Fr with a shaft crossing profile of 3 Fr [11].

The maximum recommended flow rates through the OTW lumen are 0.31 mL/s for saline and 0.047 mL/s for 76% ionic contrast media, according to the manufacturer's instructions for use. The Twin-Pass catheter is intended to be used in conjunction with steerable wires to access discrete regions of the coronary and peripheral arterial vasculature, to facilitate placement and exchange of wires, for use during two-wire procedures, and to sub-selectively deliver diagnostic or therapeutic agents.

In each of the cases, the Twin-Pass catheter was delivered upon a distally placed wire. It was advanced distal (3–5 cm) to the site of arrested flow. One to three milliliters of a solution comprising 40% contrast medium and 60% normal saline was manually injected to allow for a combination of a reduction in viscosity and adequate opacification. Repeated injections were performed following stepwise pull-back to the site of flow arrest as deemed necessary [11].

The Twin-Pass catheter also allows administration of medication to the distal bed without the risk of losing wire position in the questionable presence of a proximal dissection.

With the help of a diagnostic catheter, there are five features to be observed during distal vessel injection and stepwise proximal injections during catheter withdrawal: (1) distal antegrade flow and its briskness, (2) retrograde flow, (3) myocardial blush, (4) presence of contrast stasis in the vessel wall and evidence of an intraluminal filling defect and its type (local, globular, longitudinal dissection plane), and (5) runoff to the distal bed. The results show four distinct clinical scenarios based upon distinct pathological processes.

Classification and Management of Slow Flow

Proximal occlusive lesion The initial distal injection demonstrates brisk antegrade flow in the distal vessel with excellent runoff to the distal bed, marked myocardial blush, and no retrograde flow. Stepwise injections demonstrate a flap, thrombus, or distal stent edge dissection at the proximal occlusive site.

During PCI, any instrumentation of an arterial segment can break the integrity of the endothelial barrier and cause the formation of a thrombus. The appearance of thrombus is not the cause of the problem; it is the effect of any mechanical injury. Definitive treatment therefore needs to address these mechanical problems, such as plaque rupture, dissection, intimal denudation due to forceful jamming of a stent, distal thrombotic embolization, distal traumatic push by a tip of a wire that rolls into a ball, or intramural hematoma with opening into the lumen. In these cases, the lesions were treated with thrombus extraction (if appropriate) or stenting (if indicated) [10].

Distal vascular bed dysfunction The distal injection results in almost no antegrade flow, an absence of myocardial blush, and marked retrograde flow. The diagnosis is no-reflow due to distal microvascular spasm and obstruction. This is a diagnosis of exclusion. Treatment is with vasodilators, and prevention is by use of embolic protection devices or glycoprotein IIb/IIIa inhibitors [10].

Local dissection with or without antegrade flow With the distal wire residing in the true lumen, in the case of severe dissection with preserved antegrade flow, distal injection is associated with normal antegrade flow, good myocardial blush, and no or minimal retrograde filling. Stepwise proximal injections reveal the dissection planes with minimal contrast stasis in the vessel wall. The inflow and outflow of the dissection can also be detected. The treatment is by stenting.

In case of severe dissection with compromised flow, an absence of antegrade flow, minimal retrograde flow, no myocardial blush, and obvious stasis within the vessel wall were observed [10].

Severe distal disease If there is no gradient, however, the pullback angiography could show a distal severe lesion that was not seen by conventional antegrade angiography through the guide because the contrast could not pass the distal segment, mimicking distal no-reflow. Correction of the lesion should resolve the no-reflow phenomenon and the symptoms of the patient [10].

ACTION PLAN

The treatment includes forceful injection of blood through the guide to raise driving pressure across the capillary bed. Another approach is to inject small boluses of nitroglycerin (100–200 µg: very quick try) and/or calcium channel blockers (100–200 µg of verapamil) or adenosine (12–18 µg). Verapamil is effective in 67% of cases in alleviating arteriolar spasm and restoring antegrade flow. Nitroprusside 40 µg bolus up to 100–200 µg can also be given, and its action is seen in 2 min [12]. Epinephrine can be given, especially in patients with hypotension. The dosage ranges between 50 and 200 µg, and multiple doses can be given and adjusted according to the presence and severity of hypotension. It is important to deliver these agents into the distal artery through a balloon catheter or microcatheter. Glycoprotein IIb/IIIa inhibitors can be given as a bolus and a maintenance dose. Temporary pacing through an intracoronary wire or intravenous pacing lead and/or inotropic support is recommended or to have on standby before drug delivery into the distal artery, especially adenosine.

Adenosine

Adenosine is an endogenous purine nucleoside, a vasodilator of arteries and arterioles, and inhibits platelet activation and aggregation. Although severe bradycardia may occur due to its effect on sinoatrial and atrioventricular nodal conduction, the half-life of adenosine is very short, and these effects rarely last more than a few seconds. Prophylactic administration of intragraft adenosine does not appear to decrease the risk of slow or no reflow, but it can reverse slow or no reflow with multiple boluses. In patients who developed slow or no reflow, high doses of intragraft adenosine (five or more boluses of 24 µg each) resulted in reversal of slow or no reflow compared with low doses (fewer than five boluses). Rapid, high-velocity injections of intragraft adenosine are successful in reversing slow or no reflow and result in TIMI flow grade in the majority of cases [11].

Nitroprusside

Nitroprusside is a direct donor of nitric oxide. During SVG intervention, intracoronary administration of nitroprusside (median dose: 200 µg) resulted in significant and rapid improvement in both angiographic flow ($p < 0.01$ compared with pre-treatment angiogram) and blood flow velocity ($p < 0.01$ compared with pre-treatment angiogram). Nitroprusside was not associated with significant hypotension or other adverse clinical events but can cause profound hypotension in patients who are volume depleted or hypotensive at baseline [12].

Verapamil

Prophylactic intragraft administration of verapamil before SVG intervention tended to reduce the occurrence of no-reflow compared with placebo, increase the TIMI frame count, and improve the TIMI myocardial perfusion grade.

Nicardipine

Prophylactic intragraft administration of nicardipine, a potent arteriolar vasodilator, was followed by direct stenting for degenerated SVG without the use of a distal protection device [12].

Preparation of Nitroprusside

One ampoule of 100 mg nitroprusside (Nipride) is diluted with 250 mL of 5% dextrose in water (D5W). With a 20-mL syringe, withdraw 1 mL of the solution and fill it with 19 mL of D5W (400 µg of nitroprusside). Then give the patient a bolus of 3–4 mL (1 mL = 20 µg) [12].

AIR EMBOLISM

The incidence of air embolism should be virtually nil if meticulous safety measures are practiced. Once it happens, the patient will experience pain and hypotension similar to the occlusion of a coronary artery in AMI. A small air embolus will dissipate quickly. Air embolism typically creates a column of contrast that terminates at a site different from that of the original stenosis; 100% oxygen is the best immediate therapy.

Tips and Tricks

****Management of air embolism** Strong hand injection of contrast may help to dissipate the air bubble into the distal microvasculature. Chest pain will disappear in less than 1 min. However, a large air bubble usually moves to the relatively elevated position of the coronary artery rather than going toward the distal arteries. For example, if a large air bubble is injected into the left main, it would usually go to the LAD, which is anterior to the LCX and is likely the highest position of the coronary artery tree when the patient is in a lying position. In this situation, the operator can advance an OTW balloon, a microcatheter, an aspiration catheter, or even a small guide (5-Fr straight guide or 5-Fr multipurpose diagnostic catheter) to the air bubble and aspirate the air embolus through its central lumen [13].

****Management of massive air embolism** In a case report, 35 mL of air was injected into the left ventricle (LV) during an LV angiogram. The patient received cardiopulmonary resuscitation (CPR) for 45 min and then recovered with percutaneous cardiopulmonary support [13]. The patient should be placed in the right lateral position, a pigtail catheter advanced into the LV, and the air withdrawn while CPR continued. In a case of air embolism in the right atrium or ventricle due to air entry during subclavian or jugular vein cannulation, the patient should be put in the left lateral position so the air can be moved to the top of the right ventricle (RV) or right atrium (RA). A catheter is then inserted into the area, and the air is sucked out.

INTRAMURAL HEMATOMA

Not infrequently, after inflation of a balloon, there is fracture of the atherosclerotic plaque, including rupture of the vasa vasorum, causing formation of intraplaque, periplaque, extraluminal, and intramyocardial hematomas. The degree of compression these hematomas have on the blood flow depends on their size. The obstruction is evident as the flow is obviously impeded, although there is no sign of endoluminal dissection or thrombotic formation. The cause must be proved by IVUS.

ACTION PLAN

When ECG changes and/or chest pain occur without evidence of abrupt closure at the site of the target lesion, a number of possibilities should be considered. LM dissection can be very difficult to exclude and may require multiple projections for adequate visualization adequately. Resistance to injection, pressure damping, severe pain, and ischemia seemingly out of proportion to lesion stenosis and hypotension are indirect signs of LM obstruction. IVUS may be helpful to ascertain this diagnosis when the results of the angiogram are equivocal. Small branch occlusions can often be discovered after a detailed review comparing angiograms performed prior to the procedure side-by-side with those at the time of the event. Spasm usually appears at

(*Continued*)

the site of the balloon inflation but may appear more diffusely in the same vessel and even in other vessels distant from the site of mechanical interventions. Although often nitrate responsive, spasm may be refractory and require therapy with calcium channel blockers. Intramural hematoma is a rarely suspected cause of ischemia; a high degree of clinical suspicion enables detection of the problem by IVUS and effective treatment. The management is to stent the hemodynamically significant obstructed segment [14].

CORONARY PERFORATION

Perforation of a coronary artery with a wire can be innocuous as long as the perforation is not inadvertently enlarged by a balloon. With new devices and attempts to cross chronic total occlusions (CTOs), stiffer wires and laser wires harbor the risk that the wire will be forced through unrecognized subadventitial pathways into the true distal lumen. Subsequent dilation may then lacerate the adventitia and cause coronary perforation. In the most devastating scenario, there are actual tears or lacerations of the epicardial arteries with free communication of blood into the pericardial sac (Figure 16.6). This vessel rupture almost universally results in immediate hemodynamic collapse (Table 16.8). Without control of bleeding and drainage of the pericardial sac, fatality may result [15]. Coronary perforation causing localized epicardial hematoma can present as ST segment elevation MI due to compression of the epicardial artery [15] (Table 16.9). A unique cause can be catheter extension ejection post-angioplasty due to increased pressure behind the deflated balloon.

GAME PLAN

The treatment includes immediate inflation of the balloon at low pressure for 10 min (artery:balloon ratio 0.9:1.1) at the site of the type III perforation. Because of the catastrophic effect of perforation, it is critical for any operator to be experienced with the pericardiocentesis technique. Prolonged balloon inflation is successful in 60–70% of perforations [15]. If sealing is not successful, start giving protamine in incremental doses of 25–50 mg over 10–30 min until ACT is <150 s; this should also be done in cases of jet extravasation and cavity spilling. Pericardiocentesis must be performed if there is hemodynamic compromise. A covered stent to seal the perforation is now available in the United States (JoStent) [16]. Once there is no further dye extravasation, the patient is admitted for observation, and echocardiography should be repeated to check for further effusion. Detailed management of perforation is listed in Table 16.10. Platelet transfusion is useful to reverse the antiplatelet effect in patients treated with abciximab, but not with tirofiban or eptifibatide. However, reversal of anticoagulation could lead to acute arterial occlusion or stent thrombosis, so the risk and benefit of anticoagulant reversal should be considered carefully. When a perforation is large enough to require more than conservative treatment, two major options are available: (1) distal vessel embolization (as in some wire perforations) performed with gel foam particles, polyvinyl alcohol particles, subcutaneous fat tissues, or coils; or (2) sealing of the wall of the ruptured vessel with a covered stent [16] (Box 16.3).

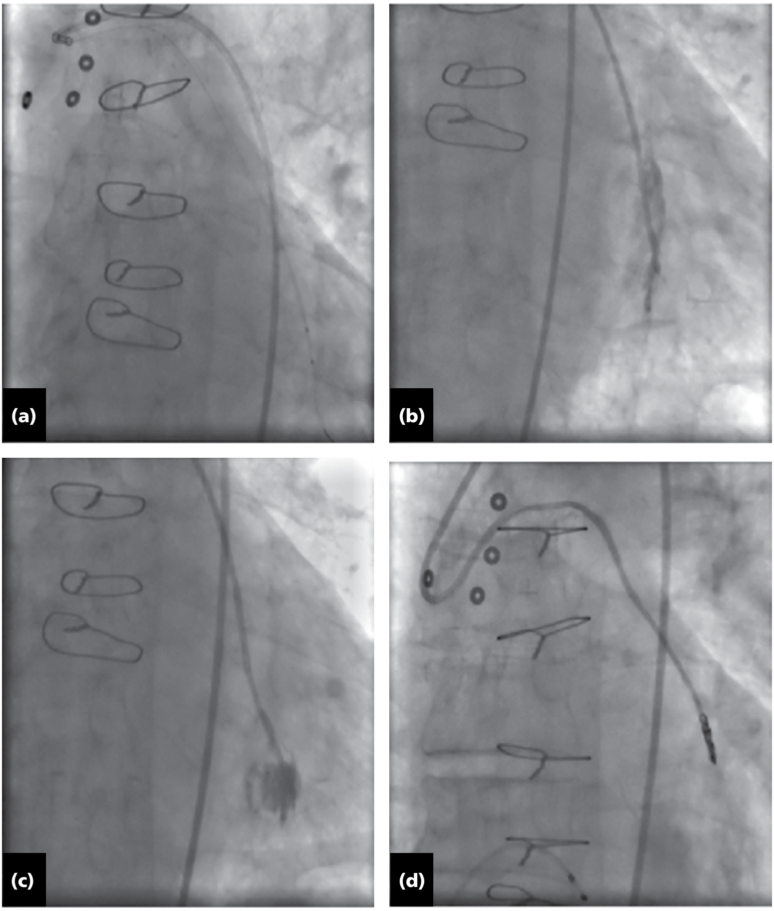


Figure 16.6 Contained coronary perforation after CABG. After balloon angioplasty with a 2-mm balloon (a), there was extravasation of contrast (b), which became more severe. (c) A coil was embolized to the distal segment and closed the perforation (d).

Table 16.8 Risk Factors for Perforation

1. Oversizing balloon (balloon:artery ratio >1.2)
2. High-pressure balloon inflation outside the stent
3. Stenting of tapering vessel
4. Stenting of contained perforations from other devices
5. Stenting of lesions that are re-crossed after severe dissection or abrupt closure
6. Stenting of total occlusion when there has been recognized or unrecognized subintimal passage of the wire
7. Stenting of small vessels (<2.6 mm)

Table 16.9 Classification of perforation

Class	Definition	Risk of tamponade
I	Extraluminal crater without contrast extravasation	8%
II	Pericardial or myocardial "blush" without contrast agent "jetting"	13%
III	Contrast agent "jetting" through a frank (>1 mm) perforation	63%

Table 16.10 Strategies in the Management of Coronary Perforation

A Step-by-step Approach

1. First: prolonged balloon inflation at low pressure, 2–6 atm for 10 min
2. Pericardiocentesis with a side-hole catheter inside the pericardial space if tamponade
3. If bleeding continues, reversal of anticoagulation:
   1 mg of protamine for every 25 units of heparin given in the previous 4 h: maximum 25–50 mg IV over 10–30 min until ACT <150 s
4. Covered stent for proximal or mid-segment of the perforated artery
5. Coil (material) embolization for perforation of distal end

BOX 16.3 TACTICAL MOVE

BEST Maneuver for Management of Perforated Vessel

1. **$ FIRST BEST Maneuver – Balloon tamponade:** Prolonged balloon tamponade at proximal segment if tolerated
2. **$ SECOND BEST Maneuver:** If sealing is unsuccessful, then reverse anticoagulation with protamine
3. **$ Add New Drug – Platelet Product:** If the distal end needs to be sealed off, inject 3–4 mL of platelet infusate at the distal perforated end through the transit catheter or through the lumen of an OTW balloon. Do not inject platelet infusate at the ostium of the main artery. The whole artery can clot. There is also a risk of delayed bleeding
4. **$$ Add New Device:** A covered stent can be used to block the opening of the side branch. Coil material can close any perforation at the distal end
5. **$ Add New Drugs:** Injection of thrombin, gelatin sponge (gel foam), or polyvinyl alcohol (PVA) foam to the distal segment to thrombose the distal vessel

Tips and Tricks

****Preventive measures against perforation by a wire** To avoid perforation, the tip of a wire is advanced gently without forcing against resistance. It should move freely. Once in the distal segment, avoid placing the tip in small branches because it can be inadvertently moved forward and perforate the artery. Its position should be checked frequently, especially when advancing or withdrawing any bulky device such as a long balloon or stent, an atherectomy device, or a long stent through a tortuous and calcified lesion.

****Preventive measures against perforation due to balloon angioplasty or stenting** After inflation of a balloon, keep the deflated balloon in place, watch for the ECG to see whether it reverses to baseline, and ask the patient to check the relief of chest pain following balloon deflation. Then make a small injection to check for severe dissection and perforation. If there is good flow distally and no obvious extravasation of blood, pull the balloon back into the guide. If there is any problem, such as dissection or perforation, the balloon is ready to be readvanced and reinflated. Do not remove the balloon unless everything is clear. Wait for more than 2 min before the next inflation for the ischemic preconditioning to kick in. If there is perforation, inflate the balloon at low pressure (Table 16.10).

****Management of perforation at the proximal and mid-segment** Treatment with prolonged balloon inflation, in some fortunate cases, may permanently cover the defect with a tissue flap and solve the problem. Nevertheless, in patients with substantial tears or lacerations, a covered stent offers a viable option. Tamponade can still happen, albeit rarely, after PCI in patients with previous CABG. The reason is that there is scar formation in the pericardial area where the pericardium was opened and removed during CABG, so there is more contained perforation, with intramuscular or mediastinal hemorrhage rather than frank bleeding or effusion (Figure 16.7). A large perforation can be successfully stopped by deploying a covered stent, if one is available. Because the polytetrafluoroethylene (PTFE)-covered stent is bulkier, the proximal segment should be predilated, the guide position should be optimal, and an extra buddy wire may be needed. The hand-crimped PTFE-covered stent should not be pushed too hard because it can slip off the balloon and embolize distally. Unfortunately, the current PTFE-covered stent has limited flexibility and a large profile, requiring an 8-Fr guide, and is not available in arterial diameters smaller than 3.0 mm.

In order to successfully deliver a covered stent, a large guide is usually required, so an exchange guide technique with a coronary wire in situ or double guide techniques should be applied according to the hemodynamic situation [17, 18].

****Double guide to advance the covered stent** If the hemodynamic status is stable after deflating the balloon that was covering the perforation, the balloon could be removed. A stiff 0.035- or 0.038-inch exchange wire should be parked in the aortic root, then a larger

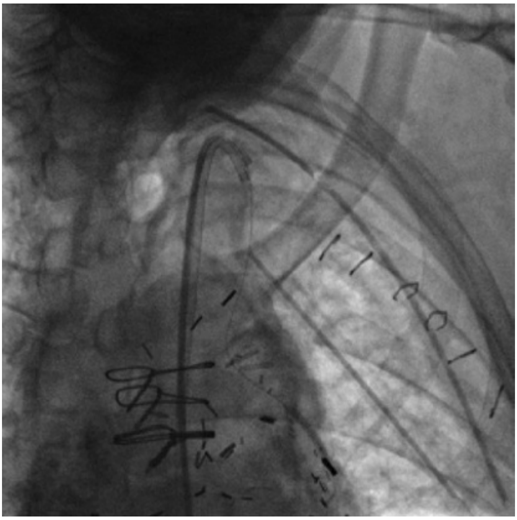


Figure 16.7 Two guide catheters are parked in the ostium of the left internal mammary artery (LIMA). The 6-Fr guide has a balloon catheter occluding LIMA flow. The 8-Fr guide will be used to deliver the covered stent.

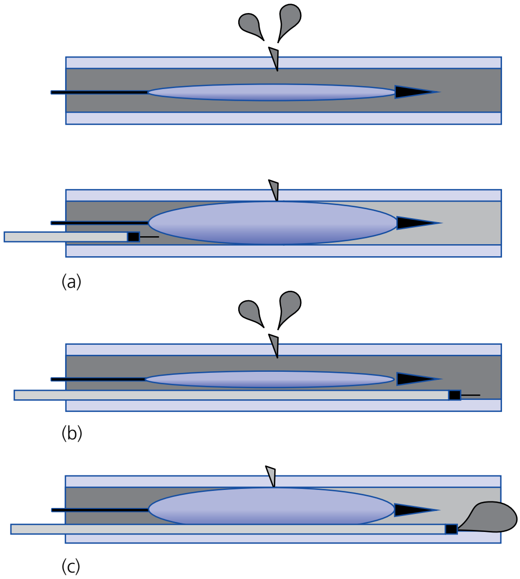


Figure 16.8 Procedure for the distal perfusion technique. (a) Insert a guide wire and microcatheter proximal to the site of balloon occlusion. (b) Deflate the balloon and quickly insert the wire and microcatheter distal to the site of perforation, then quickly reinflate the balloon. (c) During balloon occlusion, pull out the wire and inject the patient's own arterial blood via microcatheter.

guide can be exchanged while the coronary wire is still in situ with the extension wire. If the hemodynamic status is unstable and the balloon needs to be inflated to prevent further bleeding, vascular access should be established at the contralateral artery (femoral), and another guide engaged near the first guide (Figure 16.8). Through the new larger guide, another coronary wire is advanced through the perforation site while the first balloon is deflated and inflated accordingly. A covered stent can then be advanced and successfully deployed to heal the perforation. Keep in mind that a covered stent can be shortened after inflation at high pressure [19].

****Distal perfusion with a microcatheter** If the inflation of a proximal balloon causes ischemia, insert a microcatheter alongside the balloon and inject fresh blood into the distal artery (Figures 16.9 and 16.10) [17, 18].

*****How to make a covered stent with balloon material** In a case report of perforation where there is no PTFE-covered stent, cutting both ends of a lightly inflated balloon in order to create a cylinder of balloon material is suggested. Then crimp a stent over another premounted stent with the balloon cylinder in between. This results in a makeshift covered stent [16].

****Reversal of glycoprotein IIb/IIIa inhibition** The degree of platelet inhibition by the small molecule inhibitors (eptifibatide, tirofiban) is maintained through a high plasma concentration, which is proportional to platelet inhibition, so its effect disappears within 2–3 h after discontinuation of the drug. In contrast, abciximab is mostly platelet-bound with a low plasma level, so platelet infusion is needed to reverse the effect of abciximab.

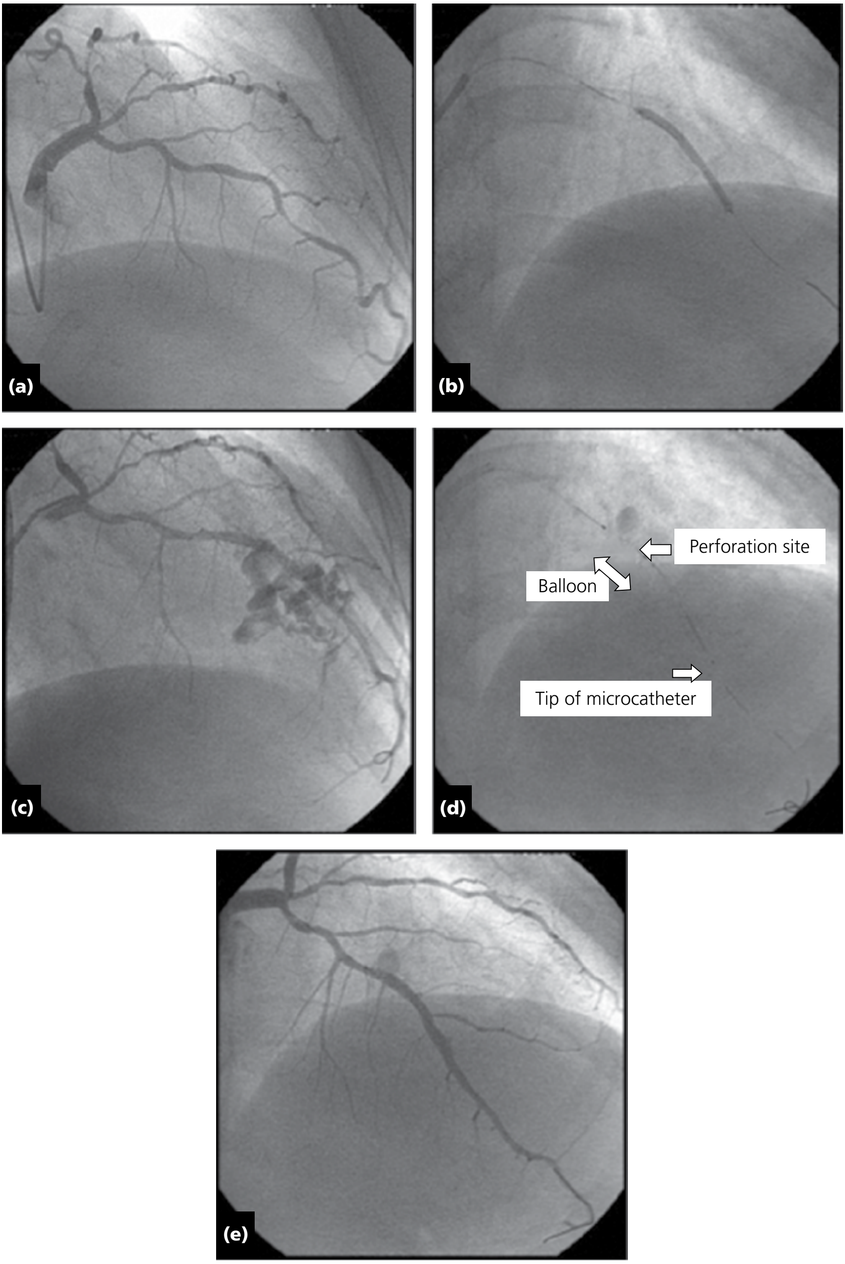

(a)
(b)
Perforation site
Balloon
Tip of microcatheter
(c)
(d)
(e)

Figure 16.9 (a–c) Coronary angiography. (d) Location of the microcatheter and balloon catheter. (e) Image from final coronary angiography. Source: Reproduced with permission from [17] / John Wiley & Sons.

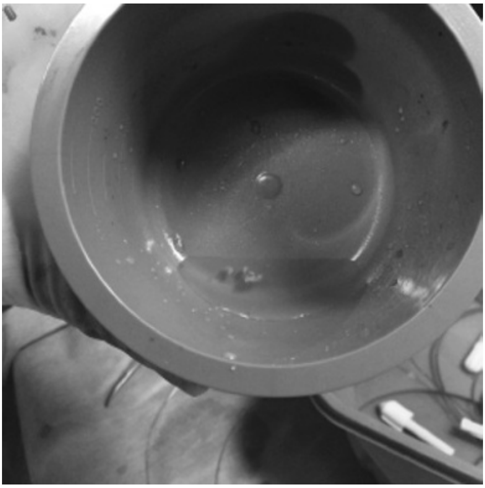


Figure 16.10 Subcutaneous fat mixed with saline in preparation for injection.

CRITICAL THINKING

Indication and Adversities Due to Reversal of Anticoagulant

A key question is whether dealing with the perforation signals the end of the case or whether the operator aims to continue the PCI procedure once control of the bleeding has been established. If the case is to be discontinued, reversal of heparin using protamine sulfate is indicated. This should, however, be deferred while equipment such as balloons and wires remain in the coronary artery. Intravenous IIb/IIIa antagonists should be discontinued in most cases where perforation is identified. The direct thrombin inhibitor bivalirudin does not have a specific antidote but has a short half-life with return of coagulation 1–2 h after discontinuation of the drug.

DISCRIMINATING DIFFERENCES

Covered stents must be used with caution in vessels with side branches, as the stent graft material may occlude the side branches. These stents may be less flexible than bare metal stents and hence harder to deliver in tortuous and calcified vessels, making their emergent use potentially challenging. As with all stents, they may not be easily deployed if the perforation occurs in a small vessel. Finally, covered stents are of limited value for perforation of the distal end-vessel.

Autologous vein-covered stents have been explored as a treatment option for coronary perforations and ruptures. However, their use is significantly limited by the complexity and time required for preparation. The process involves isolating a graft, typically from the cephalic vein, through a surgical cutdown, followed by mounting and suturing it onto a metallic stent. Given these time-consuming steps, autologous vein-covered stents are impractical for emergency situations involving free-flowing perforations and pericardial tamponade, where rapid intervention is critical. Coil embolization of coronary perforations, especially of the distal vessel, has also been used as a percutaneous bailout treatment. In general, most studies report microcoil embolization with platinum or stainless-steel coils ranging from 0.014 inch to 0.025 inch in diameter. However, larger coils have been used in coronary artery ruptures or in large segment perforations [20].

The coil size should be slightly larger than the vessel diameter to prevent dislodgement or migration of the coil. In some cases, it may be desirable to start to deploy the coil within the pericardial space and position the coil across the perforation into the native coronary artery. This may be difficult in cases where the perforation tract is small. The degree to which the coil will protrude into the coronary artery depends on the location of the perforation (e.g. distal versus mid-segment). Coils may also be used in conjunction with other treatment modalities such as localized thrombin injection [20].

DEDICATED EQUIPMENT

E

Jostent GraftMaster® Coronary Stent Graft System

The Jostent GraftMaster coronary stent graft system (Abbott, Redwood City, CA, USA) is approved by the US Food and Drug Administration (FDA) as a humanitarian use device for the treatment of free perforations, defined as free contrast extravasation into the pericardium, in native coronary vessels or saphenous vein bypass grafts >2.75 mm in diameter. The stent comes in 9, 12, 16, and 26 mm lengths and 3.0, 3.5, 4.0, 4.5, and 5.0 mm diameters. A guide of at least 7 Fr in size is required [20].

DEDICATED EQUIPMENT

E

Embolization Coils

Embolization coils and microcoils work by promoting localized thrombosis. They have been used in endovascular therapies aimed at thrombosing aneurysms (commonly intracerebral), arteriovenous fistulas, pseudoaneurysms, and perforations. The coils are typically made of metal, such as stainless steel, platinum, or platinum–tungsten alloy, which induces thrombosis and ultimately fibrosis. The basic design of an embolization coil involves a wire (usually of steel or platinum) that is wound tightly into a straight primary coil and then formed into a secondary structure of various designs (such as three-dimensional loops, helices, and spheres). The coil is usually then packaged into a delivery device and, upon extrusion, resumes its preformed shape [20].

Differences Among Coils

Stainless steel and MReye (Cook Medical, USA) coils have greater radial strength than platinum coils. However, platinum coils, being softer, may conform more easily within the vessel and theoretically can provide more optimal occlusion. Coils may be nonfibered or fibered with synthetic fibers such as Dacron® or nylon, with fibered coils being more thrombogenic and producing a greater degree of clot formation.

TECHNIQUE

Coil Embolization

Techniques for coil embolization are to some degree dependent on the device and the manufacturer. Most modern coils have device-specific instructions for deployment. However, some general techniques include (1) using the delivery device or guide for the necessary support to deliver and form a dense coil mass, (2) using high radial force coils as a scaffold upon which small, softer coils are delivered to create a dense coil mass, and (3) deploying part of the coil in a branch vessel as an anchor and then deploying the rest of the coils in the target vessel using the anchor as support. The branch vessel is sacrificed [20].

The use of some of these coils requires specialized microcatheters and small selective catheters with sufficiently small internal lumen diameter while others require specialized equipment such as coil pushers and coil-positioning catheters that allow repositioning and withdrawal of the coils prior to coil release [20].

Coil embolization is also suitable to close perforation in collateral vessels in complicated CTO cases with a retrograde approach.

TECHNIQUE

Particle Embolic Agents

Three milliliters of 250- to 355-μm Contour™ PVA embolization particles (Contour PVA, Boston Scientific or PVA Cook Medical, USA) are mixed with contrast to form a diluted, well-suspended solution, which is injected through the microcatheter into the perforated segment. The relative heaviness of the polyvinyl alcohol (PVA) particles and their delivery in the antegrade direction of the bloodstream after appropriately wedging the distal tip of a 2.9-Fr Progreat® microcatheter (Terumo, Tokyo, Japan) in the affected segment prevents any significant reflux in the small side branches as well as the major branches. The catheter must be small enough to allow selective catheterization of the vessel supplying the lesion yet be large enough to deliver an embolic agent. The particles must fit through the catheter without causing catheter occlusion yet not be so small that they pass through the capillaries [20].

An OTW balloon catheter was not considered because its maximum internal diameter is 0.36 mm compared to 0.53 mm for the microcatheter. Since the PVA particle size is 250–355 μm, the chances of lumen occlusion with an OTW balloon catheter are very high [20].

IMPROVISED EQUIPMENT

Use of gel foam (absorbable gelatin-compressed sponge prepared from purified porcine skin gelatin) and collagen with a 6-Fr Angio-Seal™ closure device (St. Jude Medical, St. Paul, MN, USA) has also been reported in similar situations. However, it must be cut to the appropriate size, which may be more difficult to deliver with precision into very small distal branches of the coronary system using a microcatheter. The use of microcoil embolization to manage coronary perforations has also been reported; however, appropriately sized microcoils must be available in catheterization laboratories for such an emergent situation. Microleak in the RCA was successfully treated with intra-arterial glue injection. However, extra caution was required to prevent setting off the glue while in transit. Platelet perfusate is also a good option [21].

Tips and Tricks

Blood clot to close the perforation Protamine was mixed with heparin, and the mixture was infused down the LAD with a peripheral balloon catheter. Unlike fat embolization, which would result in total occlusion of the vessel, in this case PCI could continue as the vessel was kept patent and the thrombus could be crossed. Subcutaneous fat is another option; however, it does require a surgical incision, and the delay can be devastating. In this case, the operators were able to use the patient's own blood to thrombose the vessel resulting in the resolution of the perforation and tamponade [22].

Fat removal In the absence of available microcoils, local anesthetic was instilled into the patient's upper thigh, and a small amount (around 5 mm in diameter) of subcutaneous fat was removed. The fat globules needed to be sufficiently small to be delivered down an Export catheter (Medtronic Inc., Minneapolis, Minnesota, USA), which has a lumen diameter of 1.04 mm; therefore, a scalpel was used to create globules of less than 1 mm in diameter, which were then mixed with normal saline. The fat could be dipped in contrast for one minute to render it radiopaque. The Export catheter was positioned just proximally to the perforation; through the catheter, a fat/saline mixture was injected with a syringe. This resulted in immediate occlusion of the diagonal artery distal to the deployed stent with successful cessation of the coronary leak [23] (Figure 16.9).

ADVANCED AND EXOTIC TECHNIQUES

Tips and Tricks

****Embolize a distal vessel with an OTW catheter** Infusion of embolization particles can be performed through an OTW balloon catheter while keeping the balloon inflated to prevent further leaks. It is important to utilize small-sized PVA particles (<300 μm) that can pass through a 0.014-inch lumen. Extreme caution is needed to prevent reflux of embolizing materials in the more proximal vessel or even to intracranial arteries in the case of guide dislocation. For this specific reason, infusion utilizing the central lumen of an OTW proximally inflated balloon may be the most appropriate approach [21].

****Occlusion of the distal artery with subcutaneous tissue** To embolize or to form thrombi in the penetrated vessel, subcutaneous tissue was planned to be delivered to the vessel. It was extracted from the incision site in the right femoral region where a sheath had been inserted. The tissue contained a great deal of fat. While the tip of the microcatheter almost completely obstructed the vessel, the tissue was put into the microcatheter and pushed with a wire until the tip of the wire protruded about 1 cm from the microcatheter. The resistance to pushing the tissue gradually decreased as the wire was advanced. After the tip of the wire had protruded from the microcatheter for 2 min, it was pulled back into the microcatheter, and the microcatheter and the wire were withdrawn from the guide. Coronary angiography showed that the small vessel was obstructed with no sign of bleeding. Subcutaneous tissue can be used as an embolization material if an autologous clot cannot be created due to a full dose of heparinization or the cardiac catheterization laboratory has no other material for embolization (microcoils, gelatin sponge, PVA, microfibrillar collagen, thrombin) [21].

Management of Perforation at the Distal End of an Artery

If the perforation is at the distal end of a large vessel or a branch, treatment consists of reversing the anticoagulation state, balloon tamponade of the more proximal segment if the patient can tolerate the ischemic injury, injection of thrombin to the distal branch, or closure of the perforated branch with embolized material (including platelet infusate, clotted blood, or coil material). The catheter should be positioned close to the perforation to avoid a large periprocedural myocardial infarction.

CRITICAL THINKING

In Case of Perforation, Which Is Better: Covered Stent or Prolonged Balloon Inflation?

After perforation, the choice is either to inflate a regular balloon with reversal of anticoagulation by heparin or to deploy a PTFE-covered stent. If the patient still needs anticoagulation to keep the just dilated or stented lesion open, a covered stent is best. If anticoagulation may not be needed after PCI, reversal of heparin and prolonged inflation of a balloon to seal off the perforation is an acceptable choice. Full reversal of heparin and prolonged ischemia due to continuous balloon inflation can cause slow flow in the distal bed or early thrombosis of the covered stent, so a covered stent should be deployed without full reversal of heparin and glycoprotein IIb/IIIa inhibition.

WARNING

The Decision to Send the Patient for CABG after Perforation

After perforation, if there is no covered stent and no embolized material, and if the bleeding does not stop after prolonged local tamponade, the patient may need surgery. However, it is not an easy and simple procedure. Often the area around the perforation has intramural hematoma, so the whole myocardial area is edematous and swollen, especially when the perforation is near the aorta (LM or proximal LAD) or in the coronary sulcus (LCX). In that situation, it is almost impossible to locate the perforated branch, so the surgeon just ligates the more proximal segment and bypasses any other diseased arteries. Surgery does not reperfuse the perforated branch that we try to save. Surgery may not be needed if the patient can clinically tolerate the closure of a small branch or the distal end of a large vessel. Important procedural considerations for prevention of perforation are listed in Table 16.11.

PERICARDIAL EFFUSION AND TAMPONADE

Pericardial effusion is the presence of fluid in the pericardial space. In the setting of PCI, fluid accumulation is abrupt, and as little as 100 mL may result in hemodynamic decompensation. The non-compliant pericardium has a steep pressure–volume curve; as intrapericardial pressure rises, the transmural pressure results in collapse of the RA first, followed by collapse of the RV

Table 16.11 Important Procedural Considerations for Prevention of Perforation

1. Constantly monitor the tip of a distal wire
2. Treat suspected perforation seriously, especially in patients on glycoprotein IIb/IIIa inhibitors
3. Do pericardiocentesis in the CCL. Insert a 5- to 6-Fr pigtail catheter for drainage
4. Local measures to seal perforation before leaving the CCL
5. Admit to ICU, frequent echocardiographic follow-up

during progressively longer portions of diastole. Compression of left-sided chambers usually occurs in severe tamponade or, in some cases, when loculation affects only a discrete portion of the left heart. There is a continuum of clinical manifestations that depends upon the speed of accumulation and the absolute volume that accumulates, as well as the underlying presence or absence of associated cardiac disease.

The presentation depends in part on at least five factors: the size of the device responsible for the perforation; the structure that is perforated, such as atrial versus ventricular myocardium, RA or LA, or RV or LV; the hemodynamic state at the time of perforation; properties of the pericardium itself; and the coagulation status. After cardiac surgery, the pericardium may be absent or adherent to the myocardial reflection and may prevent the development of tamponade, although this is universally not the case because tamponade and hemodynamic compromise can result from a posterior localized effusion (and may be particularly difficult to reach during attempted pericardiocentesis, usually requiring surgical drainage) [24].

Aggravating Factors

The pressure within the structure that is perforated is a major determinant of the development and severity of tamponade. Thus, a small perforation of the RV in an un-anticoagulated patient may not be clinically apparent; in contrast, perforation of the RV in the setting of pulmonary hypertension or anticoagulation can be catastrophic. These same considerations apply for both the RA and LA as well [24]. In addition, the device-related potential size of perforation is also crucial: a small perforation due to a coronary wire or transseptal puncture needle before giving heparin IV can be tolerated without significant hemodynamic compromise, whereas a split-like tear in cardiac structure caused by a closure-device delivery system might be fatal despite all resuscitation efforts.

Attenuating Factors

The thicker wall of the LV (≥10 mm) may act to seal small perforations, balancing the higher intra-chamber pressures. However, even a small wire perforation may not be tolerated if it occurs in patients with resistance to LV outflow, such as in severe aortic stenosis. In this case, very high LV pressure and high afterload result in the newly created hole in the chamber acting as a "pop-off" valve, with blood preferentially driven toward an initially low-pressure intrapericardial space. In contrast, a small RA perforation may be well tolerated in some patients not on anticoagulants because of low intracardiac pressures and therefore low driving pressure.

Finally, the geometry of the perforation may also be important. A slitlike perforation may result in different patterns of fluid accumulation than a circular hole, particularly if the wall of the affected chamber is thin, for example, the LA or LA appendix [24].

Clinical Presentation

The occurrence of myocardial perforation and subsequent fluid accumulation within the pericardium should be suspected clinically during the procedure after risky stages such as postdilation with high pressure, rotablation or directional atherectomy, crossing a CTO-type stiff wire through a calcified lesion, difficult transseptal puncture, dilatation of atrial trans-septum, repeated pulling and pushing of closure devices in a delivery system in the thin LA, and balloon dilatation of calcified coarctation in adult patients. The earliest sign of perforation/tamponade in PCI is usually pericardial-type chest pain, whereas the usual symptoms in congenital structural intervention are hypotension or vasovagal reactions [24] (Table 16.12).

The typical pain of new pericardial irritation is that of substernal discomfort, sometimes radiating up into the neck and jaw. Acute pericardial irritation can also present with atypical symptoms such as shoulder discomfort, abdominal discomfort, or even nausea. In some instances, the patient may describe a sense of doom even before hemodynamic changes are observed. On the other hand, the earliest finding is acute bradycardia and hypotension, reflecting a vasovagal reaction to sudden pericardial stretch with or without nausea and chest discomfort [24].

Table 16.12 **Cardiac Tamponade Characteristics**

Clinical signs of cardiac tamponade
Tachycardia or bradycardia in the early stage
Hypotension
Elevated jugular venous pressure with a blunted Y-descent
Pulsus paradoxus
Distant heart sounds
Physical features/signs of the underlying etiology (e.g. connective tissue disorders)
Enlarged cardiac silhouette on chest X-ray
Hemodynamic changes in cardiac tamponade
Hypotension
Elevation of filling pressures in all four cardiac chambers
Diastolic equalization of pressures
Blunted Y-descent in RA pressure waveform
RV and LV peak systolic pressures out of phase
Peak aortic pressure varying more than 10–12 mmHg
Decrease in cardiac output

Central aortic pressure and RA pressures can provide excellent indirect evidence of perforation and subsequent tamponade. In the very early stages, the blood pressure response is variable; although hypotension is a hallmark of tamponade, systemic aortic pressure may actually increase initially along with heart rate due to a sympathetic response to the initial pericardial irritation. However, if the tamponade is caused by a split-like tear, a rapidly accumulating blood volume in the pericardial space always presents as persistent hypotension, unchanged with crystalloid or inotropic infusion [24].

Pulse Pressure

Pulse pressure will decrease, and pulsus paradoxus will develop, reflecting an exaggerated decrease in pulse pressure during inspiration. At this time, RV filling pressures will begin to rise. The contour of the RA pressure will subsequently change during the early stages of tamponade. There will be a loss of the *y* descent and in patients who remain in sinus rhythm, there will be a more prominent *a* wave at the time of atrial contraction. As pericardial tamponade develops, there will then be a significant decrease in aortic systolic pressure and a rise in RA pressure. The pulse pressure may be so narrow during inspiration that the observer is unable to detect individual heartbeats. Intervention is indicated in the early hemodynamic stages, once there is a noticeable pulsus paradoxus, even in the absence of a drop in overall systemic pressure [24].

Chest Radiography

This may be helpful in some settings [24]. Straightening and immobility of the left heart border on fluoroscopy is a reliable and sensitive adjunctive marker of tamponade in the catheterization laboratory and occurs concomitantly with significant hemodynamic deterioration. Typically, large effusions present as a globular heart with sharp margins, sometimes referred to as a "water bottle" silhouette. If the effusion develops during catheterization, it may also be identified by the development of lucent lines in the cardiopericardial silhouette – the so-called epicardial halo sign or fat pad sign.

Echocardiography

The typical two-dimensional echocardiographic findings of RV collapse and RA invagination may not be seen in the early stages of tamponade because they require transmural pressures greater than the intracardiac chamber pressures; thus, these findings may also not be present or may be delayed in patients who have specific forms of underlying heart disease where intracardiac chamber pressures are elevated. This may be particularly the case in patients with RV hypertrophy, where pericardial fluid may not result in initial RA and RV diastolic collapse. One of the most sensitive methods for detecting early pericardial tamponade is the finding of a new septal shift on two-dimensional echocardiography, indicating ventricular interdependence. Pulse wave Doppler interrogation of the mitral inflow velocity is also important to detect early subclinical stages of tamponade, with dissociation of intrathoracic and intracardiac pressures as well as enhancement of ventricular interaction. This will result in a decrease in the initial E velocity during inspiration on the transmitral flow velocity curve. In typical tamponade, there is an overall decrease in the E:A ratio due to low early diastolic filling. However, the initial E velocity will decrease further with inspiration due to decreased filling in the left side countered by increased filling of the right side during inspiration [24].

WARNING

Tamponade without Echo-free Space

Echocardiography initially universally documents a free space. However, as anticoagulation is stopped in a specific patient or if coagulation of the pericardial fluid starts, the free space may not be as easily visible. Careful analysis of the images and hemodynamic monitoring can identify and resolve this issue.

ACTION PLAN

The treatment of iatrogenic pericardial effusion varies. Typically, when a new effusion is documented, the procedure should be terminated and any anticoagulation should be reversed. In some patients, when only a small effusion is present, these two maneuvers are sufficient to prevent hemodynamic deterioration. At the other end of the spectrum is tamponade, requiring urgent resuscitation with pericardiocentesis and placement of an indwelling catheter for continued evacuation. If there has been a tear in a cardiac structure, percutaneous drainage may not successfully resolve the problem, and surgery may rarely be required. In these situations, maintaining tamponade-related devices in situ is recommended to temporarily prevent bleeding while pericardiocentesis is performed and continuous pigtail drainage with negative pressure is established until the patient can be transferred to the cardiac operating room [24].

GAME PLAY

Pericardiocentesis

Using ultrasound guidance, the optimal window for pericardiocentesis can be determined by the apical or the subcostal approach. This is particularly true in acute tamponade, where most of the effusion is best visualized from an apical window on the posterior portion of the pericardium, necessitating an apical entry with the needle directed posteriorly. In some instances, a subcostal or lower parasternal approach is best if the effusion cannot be reached via an apical approach.

(*Continued*)

In general, the specific route for needle placement should be the route that provides the shortest and easiest access to the pericardial space. If a subxiphoid approach is used, care should be taken to avoid trauma to the left lobe of the liver. For intercostal approaches, care must be taken to place the needle superior to the specific rib margin to avoid damage to the intercostal areas. Adequate local anesthesia is important. Some operators insert a long, sheathed 16- to 18-gauge needle, whereas others prefer a micropuncture approach. Limited aspiration throughout the insertion of the needle with a 20-mL syringe is useful. Once blood is withdrawn through the needle, agitated saline should be injected under echocardiographic guidance to ensure that the entry point is within the pericardium and not within the ventricular chambers. Once the entry has been identified, the sheath is advanced into the pericardial space [24].

Although echo-directed pericardiocentesis is optimal, the procedure should not be delayed if an echo machine is not available and hemodynamic collapse is imminent. Straightening and immobility of the left heart border, especially if mobility was confirmed to be normal before transseptal puncture, is usually pathognomonic for tamponade. If the patient is rapidly deteriorating, which is usually related to severe tamponade, a "blind" pericardiocentesis, which is usually safe in severe tamponade, should be attempted via a subxiphoid or subcostal approach rather than waiting for echocardiography during hemodynamic collapse. An ordinary arterial puncture needle could be used for the subxiphoid approach in an acute setting. Through this puncture needle, a short wire is inserted into the pericardium under fluoroscopy to confirm the position of the wire, after which an ordinary 6-Fr introducer sheath is inserted into the pericardial spaces (to ensure that there is free flotation of the wire and that the course is consistent with extracardiac insertion and position). After insertion of the sheath, limited aspiration with a 20- or 50-mL syringe is required to immediately improve the hemodynamic status. An increase in blood pressure, a decrease in heart rate, and a pulsation feeling of aspiration are reliable signs of accurate pericardiocentesis [24].

With either technique, a 6- or 5-Fr pigtail catheter is inserted and connected to continuous negative pressure. In certain situations, a "cell saver" can be used so that the blood drawn from the pericardial space can be reinfused back into the patient. However, the patient can have severe pulmonary embolism if there are thrombi in the pericardial blood. The pigtail catheter can be removed 1 or 2 days later when the drainage is not significant to avoid pericarditis and reduce chest pain [24].

Intubation or at least hyperventilation should be avoided if at all possible, because the increased transthoracic pressure may lead to cardiac arrest [24]. Temporizing medical therapy is controversial: rapid infusion of fluids is advocated by most operators; dopamine or dobutamine may also be of benefit in some patients while pericardiocentesis is being performed.

Tips and Tricks

Pericardiocentesis with micropuncture kit The optimal site for pericardiocentesis is where the distance from the skin to the point of maximal pericardial fluid accumulation is shortest – typically at the apical region and secondarily via the sub-xiphoid approach – and where no intervening structures (e.g. liver or lungs) are present. A 21-gauge needle from a Micropuncture® kit (Cook Medical, Bloomington, IN) may reduce tactile feedback but can help minimize the risk of iatrogenic injury. Echocardiographic guidance enables the operator to determine and mentally map the ideal skin entry point, needle trajectory toward the heart, and the anticipated depth. Real-time imaging during needle advancement is often cumbersome and not routinely required.

Following local anesthesia, the needle is advanced slowly along the preselected path with continuous gentle suction and intermittent administration of anesthetic. Fluid return at a superficial depth may suggest inadvertent pleural or peritoneal entry, whereas absence of fluid at the expected depth necessitates needle withdrawal and adjustment of the trajectory. If a rib is encountered during the apical approach, the needle should be redirected superior to the rib to avoid the neurovascular bundle. Intermittent fluid return may indicate partial entry into the pericardial space; advancing the needle by 1–2 mm often establishes continuous drainage.

Indicators of correct catheter placement include the detection of a nonventricular pressure waveform and the appearance of agitated saline microbubbles within the pericardial sac on echocardiography (or contrast medium under fluoroscopy). In contrast, the presence of bubbles within the cardiac chambers, pleural cavity, or liver suggests wrong entries. In general, accidental puncture of the low-pressure right atrium or ventricle – except in cases of severe pulmonary hypertension – tends to self-seal after needle withdrawal. Once pericardial access is confirmed, a guidewire is introduced; its trajectory should remain within the cardiac silhouette under imaging. Features suggestive of cardiac chamber puncture include needle motion synchronized with the cardiac cycle, premature ventricular complexes, brisk blood flow from the needle, erratic guidewire movement during systole, or wire passage into the pulmonary artery or aorta. Upon confirming entry into the pericardial space, a 4-Fr dilator is advanced over the wire, followed by placement of a 0.035-inch guidewire and final catheter insertion.

Low-pressure Tamponade

Low-pressure tamponade may occur in a patient with hypovolemia during the setting of compressive pericardial effusion. Clinical findings may demonstrate a low-to-normal blood pressure with an absence of jugular venous distension or pulsus paradoxus. If low-pressure tamponade is suspected, a fluid bolus prior to invasive hemodynamic measurement may help unmask occult tamponade or constrictive pericarditis hemodynamics [24].

Tamponade with RV and LV Dysfunction

The clinical diagnosis of tamponade in a patient with pre-existing significant LV dysfunction can often be difficult. In such patients, the LV end-diastolic pressure may be elevated higher than the RV end-diastolic pressure and the intrapericardial pressure. Similarly, in patients with isolated right heart failure (e.g. chronic obstructive pulmonary disease) and elevated right end-diastolic pressure, the intrapericardial pressure will increase to equal the LV end-diastolic pressure but remain lower than the RV filling pressures. Both RV and LV dysfunction may lead to absent pulsus paradoxus. The hemodynamic diagnosis of tamponade in patients with LV dysfunction can be made when the RA and intrapericardial pressures equilibrate and track each other throughout the respiratory cycle. Likewise, in a patient with predominantly right heart failure and high RV diastolic pressures, the pulmonary capillary wedge pressure (PCWP) and intrapericardial pressure track each other throughout the respiratory cycle [24].

WARNING

Pulmonary Edema without Tamponade

In patients with poor LV function after pericardiocentesis, monitoring should focus on the development of pulmonary edema, mainly due to an abrupt increase in pulmonary blood flow and left heart filling. If the PCWP remains elevated after complete drainage, the operator should consider pre-existing cardiomyopathy. Large-volume pericardiocentesis has been reported to cause transient LV systolic dysfunction and severe RV dysfunction leading to cardiogenic shock [24]. In general, aspiration of 100–200 mL of blood tamponade in CVL is enough to restore the hemodynamics if anticoagulation is reversed and the perforation is not large.

ATYPICAL PRESENTATION

Tamponade without Pericardial Effusion by Isolated Left Atrial Compression

The diagnostic angiogram revealed a patent LAD stent with no significant restenosis, but an occlusive ISR was noted in the small LCx artery and second obtuse marginal artery [24]. Successful kissing balloon angioplasty was performed on these arteries. However, complications arose when a contained type II mid-LCx artery perforation occurred in the atrioventricular sulcus, along with a type II coronary perforation of a small atrial branch, likely due to wire positioning. Initially, the angiogram showed contained pericoronary contrast staining without leakage for 30 minutes post-procedure. The patient remained asymptomatic without hemodynamic compromise until four hours later, when severe bradycardia and hypotension developed. These symptoms were partially alleviated with intravenous fluids, atropine, and catecholamines.

A bedside transthoracic echocardiogram revealed a large hematoma adjacent to the LA without pericardial effusion, suggesting cardiac tamponade due to localized compression of the LA. The patient's instability necessitated immediate transfer to the operating room. A second echocardiogram performed just before surgery showed a significant increase in the size of the hematoma. Surgical intervention via median sternotomy confirmed a large hematoma in the atrioventricular sulcus compressing the LA. The coronary perforation was repaired using biological glue and a patch. Fortunately, the patient experienced a normal postoperative recovery.

Lesson to learn

Tamponade with hemodynamic compromise occurs rarely in patients who have previously undergone cardiac surgical procedures, partly due to partial pericardiectomy and secondary pericardial adhesions. The partial pericardial adhesions probably favor migration of the hematoma with clinical presentation at a distance from the site of perforation. The lesson here is that a hematoma can compress any cardiac chamber, causing any symptom of tamponade, without the presence of pericardial effusion [24].

ATYPICAL PRESENTATION

RV Hematoma Causing Shock

Five hours after PCI of the RCA, a patient exhibited shock (BP 60/40 mmHg) and tachycardia. Coronary angiography and right heart catheterization were done for further diagnostic clarity. The RCA was patent and without evidence of extravasation of contrast. Passage of a Swan–Ganz catheter to the pulmonary artery (PA) was very difficult, unlike the previous right heart study. Right heart catheterization revealed a pressure gradient between the PA and the RV:PA pressure 23/15 mmHg; RV pressure 53/25 mmHg; low cardiac index (CI; 1.90 L/min/m^2, previously 2.93 L/min/m^2); high mean RA pressure (26 mmHg); and cardiogenic shock with a systemic blood pressure of 48/36 mmHg. This hemodynamic collapse was treated with inotropic agents and adequate hydration, and a right ventriculogram was performed, which revealed compression of the RV outflow tract (RVOT). Thus, this hypotension was found to be a result of compression of the RVOT caused by hematoma. Pericardiocentesis was performed next to the left edge of the sternum into the hematoma. After insertion of a 6-Fr sheath, contrast medium was injected through a pigtail catheter and identified a closed cavity. A total of 411 mL blood was aspirated. Following this procedure, the pressure gradient between the PA and RV became negligible (28/17 and 30/14 mmHg, respectively; pressure gradient 2 mmHg), RA pressure fell (26–12 mmHg), and CI increased (4.17 L/min/m^2) with a rise in systemic blood pressure (104/68 mmHg) [25].

ATYPICAL PRESENTATION

Localized Tamponade Causing Right-to-Left Shunt

Bedside echocardiogram revealed a small pericardial effusion posterior to the LA and LV and no significant fluid around the RV, while the RA was not well visualized. Right heart catheterization showed normal right-sided pressures without equalization of diastolic pressures. However, the patient continued to require supplemental oxygen due to hypoxia with pulse oximetry of 85% on 4 L/min oxygen by nasal cannula. Physical examination did not reveal signs of fluid overload or congestive heart failure. Repeat echocardiogram demonstrated a large, localized pericardial effusion measuring 8 cm in diameter, surrounding and compressing the RA; hypermobile interatrial septum; and a right-to-left shunt through a patent foramen ovale by color flow Doppler and agitated saline injection. Repeat angiography confirmed TIMI 3 flow in the SVG and distal RCA with no angiographic evidence of persistent perforation. Serial bedside echocardiograms demonstrated no change in the size of pericardial effusion with persistent right-to-left interatrial shunting of blood. However, since the patient continued to exhibit significant hypoxia requiring moderate supplemental oxygen, he was ultimately referred for a pericardial window by right-sided video-assisted thoracoscopic surgical approach. Approximately 150 mL of blood was evacuated from the pericardial space with complete resolution of hypoxia. Repeat transthoracic echocardiogram demonstrated minimal pericardial fluid with no visible right-to-left interatrial shunt [26].

CEREBROVASCULAR ACCIDENT

During interventional procedures, embolization of material to the central nervous system can lead to severe complications, including transient ischemic attacks, disabling strokes, transient or permanent blindness, and seizures. The risk factors that significantly increase the likelihood of these neurological events include the use of thrombolytics prior to PCI, administration of heparin before and after PCI, low creatinine clearance, a history of cerebrovascular accidents, and diabetes. Most strokes resulting from PCI exhibit an embolic pattern (91%), with the remainder being small subcortical infarctions (9%). The middle cerebral artery (MCA) territory is most frequently affected (80%), and complete MCA territorial infarctions are associated with high mortality, as all patients with this condition died in the hospital. Among survivors, the functional outcome is generally more favorable when the stroke involves a single vascular territory rather than multiple territories. Despite periprocedural hypotension in some patients, watershed strokes indicative of a hemodynamic mechanism were not observed [27].

Once embolic stroke is confirmed, fibrinolytic drugs can be given intravenously: tissue plasminogen activator 0.9 mg/kg for a maximum of 90 mg, 10% as a bolus and the rest to be infused in 1 h [27]. Further removal of the emboli is discussed in Chapter 30.

Transient and Permanent Blindness

Occipital blindness occurs rarely and usually disappears within a few hours. However, with emboli, the patient can develop permanent blindness. The MRI findings show contrast agent extravasation without cerebral ischemia or hemorrhage. These findings are also seen in posterior leukoencephalopathy syndrome. The mechanism is a transient vasculopathy with disruption of the blood–brain barrier as a cause of transient cortical blindness after contrast angiography. The main treatment is aggressive hypertension control and symptomatic treatment of headache [28].

VENTRICULAR TACHYCARDIA AND FIBRILLATION

Cardiac arrest can be caused by ventricular tachycardia (VT), ventricular fibrillation (VF), or asystole. While the patient is being resuscitated with intubation, external cardiac massage, IABP, or pacemaker insertion, the blood pressure is usually sustained at an unacceptable level of 50–60 mmHg during CPR in a patient with asystole who shows almost no flow to the coronary system.

BEST METHOD

The One and Only Maneuver – Coronary Perfusion during CPR

During CPR, the blood pressure is low, as evidenced by aortic pressure. If there was good LV function before cardiac arrest, the chance of a good recovery is high. The interventional cardiologist can assist coronary perfusion by keeping the guide inside the LM, gently pulling it out, withdrawing oxygenated blood to a large syringe connected to the guide, and injecting this blood into the coronary system. Mix this blood with some contrast and inject it to check the flow to the distal coronary vasculature and feeble movement of the LV. With good oxygenation from the ventilator (the patient is intubated), correction of electrolyte and acid–base imbalance, and opening of the acutely occluded artery (which caused the cardiac arrest), coupled with forced coronary perfusion by injection of oxygenated blood, the chance of recovery is higher. Try not to cause dissection of the LM with movement of the guide.

Tips and Tricks

*****How to differentiate between ventricular tachycardia and supraventricular tachycardia by intracardiac ECG** To record an intracardiac ECG, a 0.014-inch ChoICE™ Floppy angioplasty wire is inserted into the lumen of a 6-Fr multipurpose catheter, ensuring the wire tip protrudes minimally. The proximal end of the wire is then connected to a surface V1 ECG lead using a sterile alligator clamp. During continuous ECG and pressure monitoring, the catheter is manually withdrawn from the RV and RA [29].

The intracardiac ECG provides valuable insights into cardiac activity. The RV ECG complex appears wider, while the RA complex is smaller. Ventricular tachycardia (VT) is characterized by a wide complex originating from the RV, often accompanied by AV dissociation. In contrast, supraventricular tachycardia typically shows RA complexes that are synchronized with the RV complexes. This technique allows for precise localization and characterization of arrhythmia, aiding in diagnosis and treatment planning.

BRADYCARDIA OR ASYSTOLE

Tips and Tricks

Pacing with a coronary wire In emergency temporary pacing via a coronary wire, adherence to key steps is critical for successful capture and patient safety. First, ensure the coronary wire tip is advanced deeply into a myocardial side branch, such as a septal perforator, rather than remaining on the epicardial surface. Second, insulate as much of the wire length as possible, ideally up to the coronary ostium, using the guide catheter. Advancing a monorail or OTW balloon catheter near the wire tip within the coronary artery can further aid insulation. Third, initiate pacing at maximum output and gradually reduce it only after consistent capture is achieved. For external connection, attach the coronary wire (acting as the cathode, or negative pole) to the pacing device. Connect the anode (positive pole) to the patient's exterior, ideally via a large skin electrode to minimize discomfort even at higher outputs. In urgent situations, a needle inserted into the anesthetized groin or even the non-anesthetized chest wall can serve as the anode for unipolar pacing [30].

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CHAPTER 17

Complex High Risk Coronary Interventions in Indicated Patients

Mihas Kodenchery, XianKai Li, Alan Fong, Nguyen Duc Cong, and Thach N. Nguyen

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*Basic; **Advanced; ***Rare, exotic, or investigational

$, <100.00 $US extra; $$, >100.00 $US extra

⌛, <10 min extra; ⌛⌛, >10 min extra

💧, low risk of complications; 💧💧, high risk of complications

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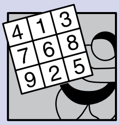
CHALLENGES

CHIP, or complex high-risk indicated percutaneous interventions, encompasses a broad range of definitions. The most widely accepted characterization describes CHIP as high-risk coronary interventions performed in patients for whom the procedure is indicated.

GAME PLAN



Routine coronary angiography with ad hoc intervention has a complication rate of less than 1% and a mortality rate below 0.1%. In contrast, CHIP procedures inherently carry a mortality risk of 3% or higher. Given this disparity, meticulous case selection is essential to ensure that CHIP is pursued only when alternative treatment modalities do not provide comparable benefits with lower morbidity and mortality risks. It is imperative to establish that, without intervention, the patient would face a significantly higher risk of mortality, morbidity, or a diminished quality of life. Physician, surgeon, and patient perspectives on treatment choices can be subject to bias. To counteract this, we employ evidence-based medicine and validated risk assessment tools to compare the risks and benefits of conservative medical therapy, CHIP, and coronary artery bypass grafting (CABG). A collaborative heart team discussion – including the patient, their family, and a cardiovascular surgeon – is crucial in determining whether CHIP is the most suitable intervention.

Many patients prefer percutaneous interventions due to their minimally invasive nature, shorter recovery times, and expedited return to daily activities. Additionally, patients often have a longstanding relationship with their interventional cardiologists, making them more inclined toward percutaneous procedures over CABG, which involves a cardiothoracic surgeon with whom they may have no prior rapport. To support informed decision-making, we provide objective comparisons of CHIP and CABG, detailing both benefits and risks. Furthermore, our CHIP program maintains a comprehensive database tracking mortality, morbidity, and vascular complications. This transparency ensures that patients and their families receive accurate, data-driven insights into expected outcomes, allowing for well-informed treatment choices.

Preprocedural Risk Assessment

Three primary factors influence both the patient's risk exposure and the physician's decision to proceed with a CHIP procedure.

Medical and Surgical Comorbidities

Although CHIP procedures target the heart, a patient's overall systemic health plays a critical role in ensuring a smooth recovery. Various medical and surgical comorbidities significantly impact procedural risks and influence the likelihood of a full recovery. These include diabetes, chronic lung disease, chronic kidney disease, severe anemia, severe contrast allergies, recent stroke, severe coagulopathy, advanced age, frailty, and metastatic cancer.

Cardiovascular Comorbidities

CHIP procedures are often associated with acute and unpredictable hemodynamic fluctuations. The heart's ability to tolerate and recover from these changes depends on multiple factors, including ejection fraction, the extent of stunned myocardium, compensatory reserve from unobstructed coronary arteries, the presence of valvular disease, left ventricular end-diastolic pressure (LVEDP), diastolic function, and pulmonary artery pressures. If cardiac reserve is deemed insufficient to withstand potential hemodynamic compromise, mechanical circulatory support (MCS) may be considered an adjunct to safely complete the procedure. Common cardiovascular comorbidities that can affect CHIP outcomes include atrial fibrillation, recent heart failure (within 2 weeks), heart failure classified by the New York Heart Association (NYHA) classification, angina categorized by the Canadian Cardiac Society (CCS) classification, cardiogenic shock, history of cardiac arrest, preprocedural vasopressor use, aortic stenosis, severe peripheral arterial disease (PAD), severe pulmonary arterial hypertension (PAH), decompensated heart failure, severe valvular heart disease, moderate to severe mitral regurgitation (MR), and left ventricular aneurysm.

Anatomical Factors in Coronary Artery Disease

One of the primary challenges interventional cardiologists' faces is the complexity of coronary anatomy. In our experience, the most significant obstacles to successful revascularization include coronary calcifications, chronic total occlusions (CTO), severe side branch disease in bifurcation, and marked tortuosity. Key procedural risk factors include interventions in saphenous vein grafts (SVG), unprotected left main (LM) disease, bifurcation with major side branch involvement, severe calcification, CTO interventions, use of MCS, coronary thrombosis, three-vessel disease, interventions on the last remaining conduit, and pronounced tortuosity.

Technical Factors Associated with Coronary Intervention

Several technical aspects of coronary intervention inherently increase procedural risk. These include atherectomy, CTO interventions, use of MCS, covered stents, intravascular ultrasound (IVUS), specialized coronary wires, intracoronary physiology assessment, guide catheter extensions, and embolic protection devices.

Role of Mechanical Circulatory Support Devices

The advent of MCS devices has significantly improved both operator confidence and patient hemodynamic stability during high-risk interventions. However, operators must carefully weigh the benefits of MCS against the increased risk of vascular complications associated with large-bore access. To facilitate objective decision-making, we document the medical indications for MCS use and have developed a scoring system to optimize patient selection while minimizing unnecessary risk.

Indications for MCS include complex coronary anatomy, extensive myocardial territory at risk, prolonged procedural duration, need for advanced coronary techniques, underlying left ventricular dysfunction, compromised cardiac and systemic hemodynamics, cardiogenic shock, history of cardiac arrest, and significant medical or surgical comorbidities. Severe coronary artery disease is particularly concerning in cases involving multivessel disease, percutaneous coronary intervention (PCI) of the last available conduit, and unprotected or distal LM disease. Predictors of hemodynamic instability during CHIP include mild to severe left ventricular ejection fraction (LVEF) depression, borderline hemodynamic parameters, elevated LVEDP, and severe valvular regurgitation (Table 17.1).

Table 17.1 **Objectivizing the indications for mechanical circulatory support**

Variables	Score
Cardiogenic shock or CPO<0.6	+2
Syntax score >22	+1
LVEF <35%	+1
LVEF <25%	+2
SBP <100 or on pressors	+1
ACS presentation	+1
Planned revascularization of >2 territories	+1
PCI of unprotected left main requiring atherectomy + severe right coronary artery (RCA) disease with or without left to right collaterals	+2
Last remaining conduit	+2
Likely prolonged ischemia; retrograde PCI, atherectomy, shock wave	+1
Severe valvular heart disease	+1
LVEDP >19	+1
LVEDP >25	+2

Interpretation of MCS score:

2	Unlikely to need mechanical circulatory support (MCS) device
3–6	Be prepared to use MCS device as a backup. It is our practice in the lab to have an alternative access ready for insertion of MCS device in the event of hemodynamic or electrical instability or an unanticipated complication
>6	Recommend upfront use of MCS device for the procedure

The following additional clinical, anatomical, and technical variables are helpful in making decisions regarding upfront use of mechanical circulatory devices during percutaneous coronary intervention when the MCS score is borderline.

Severely reduced LVEF <20%,
Severely ischemic cardiomyopathy
Acute decompensated heart failure
Recent acute coronary syndrome
Markedly elevated LVEDP
Severe multivessel coronary artery disease with chronic total occlusion
Heavily calcified coronary arteries
Complex PCI of unprotected left main or last remaining vessel

BEST PLAYERS

Establishing a Successful CHIP Program

A successful CHIP program requires a multidisciplinary team approach. While an experienced interventional cardiologist is central, the program's success depends on collaboration with a skilled cardiothoracic surgeon, catheterization laboratory staff, recovery team, intensive care unit personnel, cardiac step-down unit, rehabilitation team, and physician extenders such as nurse practitioners and physician assistants. In our program, 90% of CHIP patients are transferred to the cardiac step-down unit and discharged within 48 hours post-procedure. Challenges such as staff shortages and high nursing turnover have necessitated strategic adaptations. To mitigate the risk of postoperative bleeding complications associated with large-bore sheaths, we implemented the Early Bird Bleed Monitoring System (EBBMS; Saranas, Houston, TX) and standardized protocols, enhancing early detection and management while ensuring patient safety and program sustainability.

Role of anesthesia The heart team, in collaboration with the catheterization laboratory nursing staff, evaluates each patient's ability to tolerate prolonged procedures under sedation. Factors such as advanced age, high anxiety, borderline hemodynamics, poor compliance and insight, chronic pain, compromised lung function, and dependence on narcotics, benzodiazepines, or other medications are poor predictors of tolerance to conscious sedation. For these patients, anesthesiologists conduct further assessments and arrange for general anesthesia or monitored anesthesia care (MAC). As the volume of CHIP interventions has increased, we have successfully established an anesthesia service line dedicated to cardiovascular services.

Cardiothoracic surgery backup It is neither practical nor financially feasible to have a cardiothoracic surgeon and a full perfusion team on standby in the catheterization laboratory for every CHIP procedure. The Randomized Trial to Compare Percutaneous Coronary Intervention between Massachusetts Hospitals with Cardiac Surgery On-Site and Community Hospitals without Cardiac Surgery On-Site (MASS COMM) trial, which compared PCI outcomes at facilities with and without on-site cardiac surgery, found no significant difference in the need for emergency surgery (0.3% versus 0.1%) [1]. Additionally, a meta-analysis of multiple clinical trials and registries reported an emergent CABG rate of 0.5% [2]. Predictors for emergent CABG during CHIP include impaired left ventricular function, cardiogenic shock, female sex, CTO, proximal lesions, severe vessel tortuosity, extensive calcification, bifurcation lesions, and complex right coronary artery (RCA) disease. Other risk factors include complex coronary anatomy, peripheral vascular disease, heart failure, stroke, hypertension, hemodialysis, connective tissue disorders, lung disease, and obesity. Scoring systems have been developed to predict the need for emergent surgical support. Even among the highest-risk patients, the incidence of emergent surgery remains low (0.6%). The ECABG score considers factors such as age, coronary artery disease complexity, peripheral vascular disease, history of heart failure, previous stroke, hypertension, hemodialysis, connective tissue disease, chronic lung disease, and morbid obesity to estimate the risk of emergent CABG within 24 hours of elective PCI [3]. This score stratifies patients into low-, moderate-, and high-risk groups, allowing for better allocation of cardiothoracic surgical resources. However, these scoring systems tend to overestimate surgical needs.

Prerequisites of cardiac catheterization laboratories High-quality imaging and digital archiving systems should be standard in all catheterization laboratories. Fixed, mounted fluoroscopy systems are preferred over mobile C-arm fluoroscopy machines. Portable ultrasound machines, operated by trained personnel, should be available for vascular access, emergency ventricular function assessment, and exclusion of pericardial tamponade. Essential resuscitation equipment, including emergency airway kits, cardiac arrest medications, vasoactive agents, and defibrillators, must be readily accessible. Intravascular imaging and physiological assessment tools are critical for guiding PCI and minimizing complications. Additionally, laboratories must maintain an inventory of interventional and rescue equipment, including guide catheters, guide extension catheters, balloons, stents, thrombectomy and distal protection devices, covered stents, temporary pacemakers, and pericardiocentesis trays. At a minimum, an intra-aortic balloon pump should be available, and institutions performing complex PCI should also have access to percutaneous left ventricular assist devices.

The Society for Cardiovascular Angiography and Interventions (SCAI) classifies institutions into Level 1 and Level 2 centers, distinguishing those without on-site surgical backup from those with such support. Our institution provides Level 2 interventional services with limited cardiothoracic surgery backup, as our cardiothoracic department is managed by a single surgeon and a single operating room (OR) team capable of supporting emergent open-heart surgery. This model is common in many busy community hospitals, where a single cardiothoracic surgeon supports growing interventional services amid a nationwide shortage of cardiothoracic surgeons and declining surgical volumes.

CONFRONTING THE CHALLENGES

Access

The success of CHIP is highly dependent on high-quality vascular access.

We employ a combination of manual palpation, fluoroscopy, and ultrasound for optimal access. Initially, we palpate the femoral pulse manually, marking the upper and lower ends of the femoral head on the skin. Using ultrasound guidance, we identify the bifurcation of the femoral artery and trace it upward to locate the point where the artery dips into the pelvis. A micropuncture needle is then used to obtain access. Ideal access is at least 10 mm above the femoral artery bifurcation, overlying the lower half of the femoral head, and free from plaque, calcification, or luminal narrowing. The entry angle should be 40° to 60° at the anterior wall. After confirming needle position via palpation, fluoroscopy is used to verify proper anatomical entry. If acceptable, the needle is withdrawn, and a micropuncture dilator is introduced. It is crucial to ensure that the dilator tip remains free and does not embed in the vessel wall or plaque to prevent retrograde dissection and complications.

An ipsilateral anterior oblique angiogram is performed to further assess access. If deemed acceptable, the dilator is rewired, exchanged for a micropuncture sheath, and removed. The procedure is then guided by a long J-wire. At this point, 5000 units of heparin are typically administered. In all CHIP patients, up to four access points are obtained: bilateral arterial and venous sheaths. One arterial sheath is used for intervention, typically upgraded to a 7-F sheath, while the second arterial sheath is upgraded to an 8-F sheath for MCS. A long J-wire is employed to access the ascending aorta, with careful monitoring of wire position by marking the wire tip on the drape.

BEST PLAYERS

Arterial and Venous Access

The right venous sheath is typically reserved for the interventionalist to facilitate transvenous pacing or other resuscitative measures. The left venous sheath is assigned to the monitoring nurse or anesthesiologist for central monitoring and medication administration, ensuring reliable intravenous access. In cases of significant iliac tortuosity, direct access to the aorta is achieved using a long, often braided sheath. If a Manta (Teleflex Inc, PA, USA) closure device is planned, femoral artery depth is measured using a depth locator.

The wire is then exchanged for a stiff wire, such as an Amplatz wire (Boston Scientific, Natick, MA, USA), and the MCS device dilator is used to facilitate large-bore access. The smooth transition of the Impella dilator (Abiomed, Danvers, MA, USA) to a 14-F sheath eliminates the need for serial dilations. Once the large-bore sheath is inserted and flushed, an additional weight-based dose of heparin is administered. The aortic valve is then crossed, and LVEDP is measured. An LVEDP greater than 19 mmHg often indicates the need for MCS during intervention, while an LVEDP greater than 26 mmHg typically predicts major complications during CHIP.

GUIDE SELECTION

The choice of guide in CHIP cases is critical to the success of the procedure. Guides must be large enough to provide adequate support, facilitate the use of secondary support devices such as the Guideliner (Vascular Solutions, Minneapolis, MN, USA), and enable the simultaneous delivery of multiple balloons and stents. Guides should ideally engage in the coronary artery coaxially. If possible, side-hole guides are preferred, as they allow for deep seating of the guide during CHIP interventions. However, side-hole guides come with certain drawbacks, including compromised guide strength, poor angiographic clarity, and increased difficulty when dealing with heavily calcified arteries, CTO, or long vessels such as the left internal mammary artery (LIMA) to the left anterior descending (LAD) artery.

Tips and Tricks

****Preferential selection of guides** For left coronary interventions, the 7-F EBU guide (Medtronic, Dublin, Ireland) with side holes is commonly used, while for RCA interventions, the 7-F JR 4 guide with side holes is preferred. JR guides, while coaxial to the artery, provide limited support in complex interventions. More supportive guides, such as the AL 1 and RBU, are also used. However, these guides often pose challenges when engaging the RCA in the presence of an Impella device (Abiomed, Danvers, MA, USA) positioned in the ascending aorta. The convexity of the Impella catheter can obstruct access to the RCA ostium. Even when successful guide engagement is achieved, the close proximity of the Impella catheter often leads to manipulation of one catheter causing displacement of the other.

****Manipulations of the guide in the presence of the impella** The position of the JR 4 guide in relation to the Impella shaft is also crucial. Care must be taken to maintain the JR guide in a left lateral position relative to the Impella catheter as it descends into the ascending aorta. If the JR guide moves medially to the Impella catheter, guide manipulation becomes challenging, and deep engagement of the artery is often not possible. Furthermore, significant interference between the catheters may occur. In some cases, the Impella prevents the guide from engaging the artery entirely. In such instances, we retract the Impella into the ascending aorta, engage the guide, wire the artery, and then reinsert the Impella into the left ventricle (LV).

WIRE SELECTION

When the guide is not sufficiently supportive, after wiring the lesion and performing plaque modification with a microcatheter, the workhorse wire can be exchanged for a more supportive wire, such as the IronMan wire (IronMan, Abbott Vascular), Redwood City, CA. A Guideliner is then advanced over the supportive wire. If there is difficulty advancing the Guideliner, the balloon anchoring technique can be employed. This involves inflating a small balloon at very low pressure distal to the Guideliner, allowing the Guideliner to advance as the balloon deflates. This technique helps to center the Guideliner within the vessel lumen, facilitating its advancement.

An alternative technique, known as the "earthworm technique," involves inflating a balloon distal to the Guideliner, then rapidly deflating and pulling it back, which creates a vacuum that draws the Guideliner inward. However, we have found this technique to be less effective.

At times, it may be necessary to advance the guide over the Guideliner to achieve deep seating in the artery, providing additional support for device delivery. These maneuvers carry inherent risks, requiring careful decision-making by the operator. The primary concerns include pressure dampening, ventricularization, and potential loss of pressure at the guide tip. When these complications occur, a timer is initiated to monitor the duration of ischemia, with the goal of delivering the stent and resolving the issue quickly. Side holes in the guide can help maintain perfusion in such circumstances.

In patients with advanced ischemic cardiomyopathy, these complications are often associated with loss of pulsatility, ST elevation, and ischemic arrhythmias. In patients with high LVEDP, worsening pulmonary edema and oxygenation may also occur. Our experience suggests that if these invasive maneuvers are limited to less than 3 minutes, they are generally well tolerated. In some cases, it may be necessary to withdraw all catheters, allow time for reperfusion and stabilization of hemodynamics, and then resume the procedure. The extent of iatrogenic injury is assessed through post-procedure electrocardiograms (EKG), troponin levels, and lactic acid measurements 2 hours post-procedure, with follow-up troponin and EKG performed the next day (Videos 17.1 and 17.2).

Video 17.1 Abnormal position of EBU leading to iatrogenic aortic regurgitation and cardiac arrest.

Video 17.2 Manipulation of the EBU guide to more coaxial position leads to correction of amplatz left and return of spontaneous circulation.

Anticoagulation Except in cases of CHIP associated with STEMI or extensive clot burden, interventions are typically performed with unfractionated heparin (UFH). Its ability to be monitored and reversed with an antidote makes it our preferred choice. We aim to achieve an activated clotting time (ACT) of 250 at the time of MCS insertion and maintain an ACT between 250 and 300 during coronary interventions. Additionally, we strive to keep the ACT below 300 during closure. As part of our standard practice, we administer approximately 5000 units after achieving bilateral access, followed by an additional 3000 to 5000 units upon upgrading to a large-bore sheath, depending on the patient's size. Additional glycoprotein IIb/IIIa inhibitors are used if complications such as thrombus, dissection, poor outflow, or difficulty loading the patient with dual antiplatelets occur at the conclusion of the procedure.

Tips and Tricks

__**How to wire acutely angulated vessel__ This challenge is commonly observed in LM bifurcations, particularly with the left circumflex artery (LCX). It becomes even more complex when an ostial lesion or a lesion following an acute bend is present. A double-bend technique is frequently employed for wire navigation. The length and orientation of the bend are determined by the anatomy. To control the wire's direction, we prefer a bend that mirrors the angle of origin of the branch, with the bend length exceeding 50% of the main vessel's diameter. For directing and regulating force, a short, 1-mm bend, similar to those used in CTO lesions, is preferred. Double bends are utilized when significant angulation of the branch is encountered. In this approach, the first bend is small and directs the wire, while the second bend, spanning more than 50% of the main vessel's diameter, is used to engage the branch. Acute bends offer the advantage of being better maintained, even in tortuous vessels, while smooth bends can be straightened by rapidly rotating the wire. Microcatheters can be used to assist in straightening the wire bends. Additional strategies that facilitate access to acutely angulated vessels include inflating a balloon in the main vessel at low pressure, as well as the use of Twin-Pass (Vascular Solution) and Venture catheters (Velocimed, Minneapolis, MN, USA) (Videos 17.3 and 17.4)

Video 17.3 Wiring angulated branch using Venture catheter.

Video 17.4 Wiring severely angulated left circumflex artery using a Twin Pass catheter. (Left main and left anterior descending (LAD) artery are wired, the Twin Pass catheter is advanced over the LAD wire using the Rx port, and the proximal port of the catheter is placed at the ostium of the angulated circumflex and wired using a second wire through the over-the-wire (OTW) port.)

****Wiring through a previous stent** CHIP cases generally present a higher incidence of in-stent stenosis (ISR) and stent thrombosis. When initiating a CHIP procedure, it is inevitable that operators will need to wire previously deployed stents. The difficulty of wiring depends on factors such as the duration of stent placement, the degree of stent reendothelialization, under-expansion, malapposition, stent overlap, and longitudinal stent distortion. These factors can complicate the process, as the wire may tend to pass beneath a stent or through a strut. Strategies such as wiring with a preformed loop, using a support catheter, or employing an over-the-wire (OTW) balloon are helpful in overcoming these challenges. In refractory cases, a Twin-Pass or thrombectomy catheter may be necessary. If the wire has passed under a strut of a previously deployed stent, the thrombectomy or Twin-Pass catheter can be advanced through the Rx port until the catheter is stopped by the stent. A different wire with an acute bend at the tip should then be advanced through the OTW port of the Twin-Pass or the thrombectomy catheter's aspiration port. Specialized catheters, such as the Venture (Velocimed, Minneapolis, MN, USA) or Ninja catheters (Merit Medical Systems, USA), with navigable tips, or precurved options like SuperCross catheters (Vascular Solutions, Inc., Minneapolis, Minnesota, USA), can also provide alternative solutions (Video 17.5).

Video 17.5 Patient with STEMI due to stent thrombosis of a recently deployed stent. Significant difficulty in wiring due to the propensity of the wire to go outside the stent. Finally, true lumen was wired using the technique mentioned above with twin pass catheter and intervention was successfully completed and flow was established in the left anterior descending artery.

****Severe calcification** Severely calcified vessels present a significant challenge for both wiring and device delivery and are associated with an elevated risk of failure, dissection, and perforation. In our practice, after wiring, we begin with the IVUS catheter. If the IVUS catheter successfully crosses the lesion, we proceed with noncompliant balloon inflation or intravascular lithotripsy for plaque modification. However, if the IVUS catheter fails to cross or if there is extensive calcium observed in all quadrants, we opt for atherectomy. It is also crucial to recognize that angiographically visible stenosis may not always align with the actual location of calcification in the vessel. Often, we observe proximal calcified spicules projecting into the lumen that, while not obstructive on their own, may hinder the delivery of a stent to the target lesion later. Consequently, our approach is to initiate atherectomy at the point where the IVUS catheter encounters resistance, even if the lesion does not appear obstructive on angiography.

****Tortuous vessels** With advanced age and hypertension, the incidence and severity of tortuous blood vessels progressively increase. Tortuous iliac arteries and the aorta present significant challenges in the advancement of large-bore sheaths, mechanical circulatory devices, guide manipulation, and the delivery of stents and balloons. In cases of tortuous iliac arteries, we use a long standard Glidewire (Vascutek Terumo, Japan) and an angled Glide catheter (Vascular Solutions), which is subsequently exchanged for an Amplatz or Lunderquist wire (Cook medical, Inc., Bloomington, IN, USA). The large-bore 14-F sheath is then advanced over the stiff wire into position. In instances where the iliac arteries and aorta are highly tortuous, the large-bore sheath may kink, complicating the delivery of mechanical circulatory devices, such as the Impella (Abiomed, Danvers, MA, USA). To address this, we advance the Impella catheter until the kink is encountered and then stabilize the Impella catheter in position. The sheath is then carefully withdrawn over the Impella catheter under fluoroscopy until the drive is positioned beyond the kink in the sheath (Video 17.6).

Video 17.6 Negotiating Impella through a kinked sheath from severe aortoiliac tortuosity.

When aortoiliac tortuosity interferes with guide manipulation, using a 25-cm or 60-cm sheath can be helpful. Another effective maneuver involves leaving an Amplatz or Lunderquist wire in place through most of the guide, allowing manipulation to engage the coronary arteries before removing the wire once engagement is achieved. When the coronary artery itself is tortuous, wire manipulation can be extremely difficult, especially if a critical lesion is located just beyond an acute bend. We have found several useful techniques in these cases: wiring with a support catheter, such as Teleport (Abbott Inc., IL, USA), FineCross (TERUMO, Tokyo, Japan), or SuperCross with angulation (Teleflex, PA, USA); using a steerable catheter, such as the Venture or Ninja catheter, to direct the wire; or employing a two-wire technique. In the two-wire technique, the first wire is placed as close to the lesion as possible to reduce angulation, followed by a second wire to cross the lesion. In highly tortuous vessels, after wiring with a workhorse wire, we often use an exchange catheter to replace the workhorse wire with a supportive wire, such as IronMan (Abbott Inc., IL, USA) or MailMan (Boston Scientific, Marlborough, MA). These maneuvers, however, carry risks. The wire tip should avoid small branches, and looping the IronMan wire should be strictly avoided. It is critical to visualize the wire tip when feeding any device over the IronMan wire, as improper manipulation can lead to vessel perforation. Most wire perforations in our experience have been intramyocardial and non-consequential. However, straightening a highly tortuous vessel may sometimes lead to no-reflow phenomena and pressure dampening. In such cases, the intervention should ideally be completed within 3 minutes. Additionally, pseudo-lesions may complicate the angiographic assessment, and no-reflow may prevent further angiographic guidance. In this situation, intervention should proceed with angioplasty and stenting based on clinical judgment or IVUS guidance. Once the lesion is successfully addressed, the wire can be pulled back to the supportive position within the guide or exchanged for a softer wire, followed by imaging (Video 17.7).

Video 17.7 Tortuous right coronary no flow with stiff wire.

ATHERECTOMY

Atherectomy devices are among the most powerful tools in our CHIP armamentarium. The operator's proficiency and comfort in performing atherectomy across various coronary anatomies significantly enhance the likelihood of delivering a well-apposed and adequately expanded stent, thus optimizing interventional outcomes. Several challenges, such as ostial lesions, diffuse and heavily calcified critical stenosis, and highly tortuous vessels, can complicate the procedure. In our catheterization laboratory, rotational and orbital atherectomy, as well as intravascular lithotripsy, are commonly used. Our experience with laser atherectomy is more limited. In cases involving ostial lesions, the Rotablator (Boston Scientific, Marlborough, MA, USA) may be a preferred option; however, in very tight or long lesions, there is a higher risk of the device becoming trapped proximal or distal to the lesion, as the Rotablator lacks retrograde atherectomy capability. For tight lesions, slow, back-and-forth motion with the burr, advancing only when it can reach a speed of 120 000 rpm or higher, is often effective. Orbital atherectomy devices, which operate in both anterograde and retrograde motions, present a slightly lower risk of the burr becoming stuck. In ostial and tortuous anatomies, we set the device knob to the middle position and advance it with glide assist until beyond the lesion and tortuous segment, performing atherectomy during the return pass. This technique helps mitigate the risk of the burr jumping. Orbital atherectomy should be advanced and withdrawn at a rate of less than 1 mm/s to avoid increasing the risk of perforation, dissection, and no-reflow. It is crucial to release any built-up torque and tension in the system before initiating atherectomy. When performing anterograde atherectomy, place the nose cone at least 5 mm proximal to the lesion; for retrograde atherectomy, position it 5 mm distal to the lesion. After confirming the correct positioning, it is beneficial to place the device in glide assist mode and advance and retract the burr to release any tension in the catheter, thereby preventing the burr from jumping forward when atherectomy begins. When performing atherectomy in a proximal vessel, it is crucial to maintain steady forward pressure on the guide. In cases where severe ostial lesions prevent the burr from advancing and instead cause the entire system to move backward, a strategic approach is necessary. To overcome this challenge, we withdraw the device, adjust the guide to align the burr precisely with the ostium, and then initiate the procedure approximately 10–15 mm proximal to the lesion. This technique ensures that the device is fully accelerated, gains sufficient momentum, and strikes the lesion centrally. By doing so, we significantly increase the likelihood of achieving a successful outcome (Video 17.8).

Video 17.8 1. In a tight ostial circumflex lesion with short left main. 2. The entire system is pushed back as the orbital atherectomy is attempted to be advanced. 3. It is possible to use a Guideliner to deliver the orbital atherectomy device to the site of the lesion for support and then withdraw the Guideliner before starting orbital atherectomy.

BIFURCATION LESIONS

Bifurcation lesions are inherently challenging due to the risks of compromising side branch flow, branch closure, and the elevated likelihood of in-stent restenosis and stent thrombosis. Provisional stenting is the preferred strategy for most lesions; however, a two-stent strategy should be considered for true bifurcation lesions (e.g. 1,1,1 and 0,1,1 configurations), distal LM bifurcation, when the non-LM side branch stenosis exceeds 90%, LM branch stenosis exceeds 70%, or when the lesion length is 10 mm or greater. Most two-stent strategies require rewiring through the jailed branch within the stent, a procedure that can be technically challenging and, if unsuccessful, may lead to catastrophic outcomes. We have successfully employed the jailed stent balloon technique for most LM bifurcation stentings. In this approach, the jailed stent balloon helps protect the side branch stent ostium. If the angiographic results are acceptable with TIMI 3 flow, rewiring through the stent can often be avoided (Figures 17.1 to 17.5 and Video 17.9).

Video 17.9 Final angiogram.

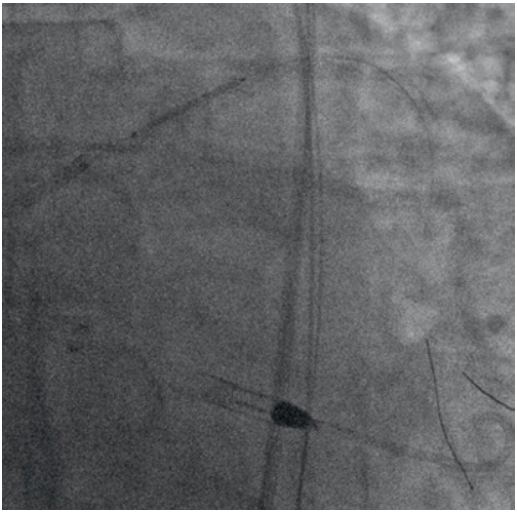


Figure 17.1 Main branch stent position.

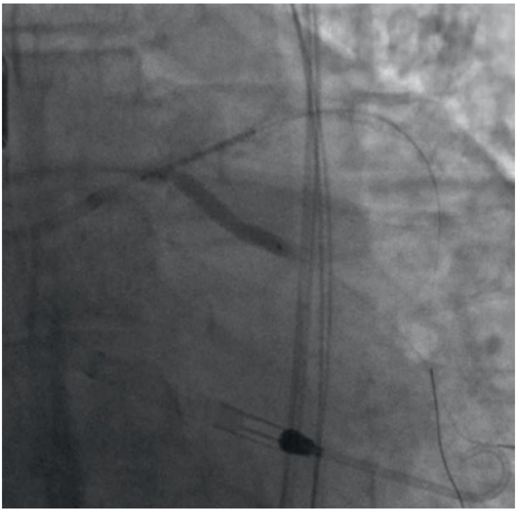


Figure 17.2 Side branch stent deployment.

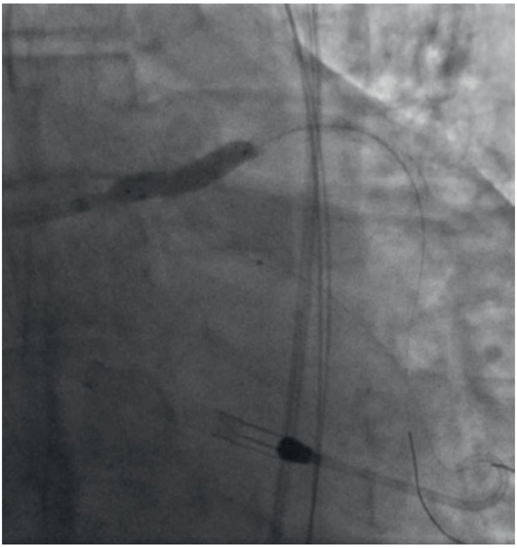


Figure 17.3 Main branch stent deployment with trapped stent balloon.

Inability to Pass Balloon after Wiring

The following strategies are considered in balloon uncrossable vessel. This is common in CTOs. But it is also seen in heavily calcified vessels with diffuse critical stenosis (Table 17.2).

Our standard approach involves advancing a microcatheter, such as the Tornus (Asahi Intecc, Aichi, Japan), Corsair (Asahi Intecc, Nagoya, Japan), or Teleport (Abbott Inc., IL, USA). The Teleport is advanced to the uncrossable lesion, where the wire is secured between the ring and

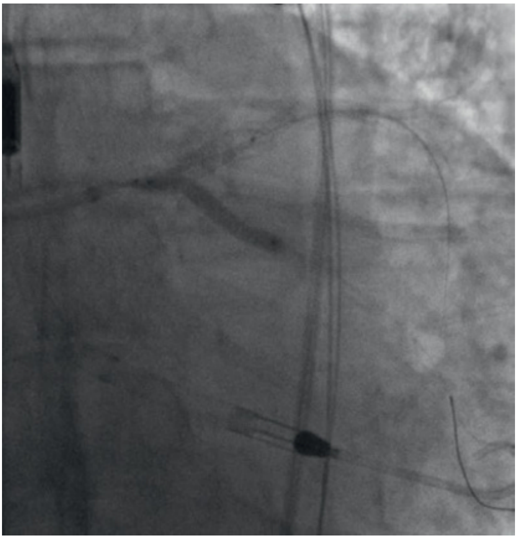


Figure 17.4 Side branch stent balloon is partially withdrawn and inflated to correct the side branch ostium.

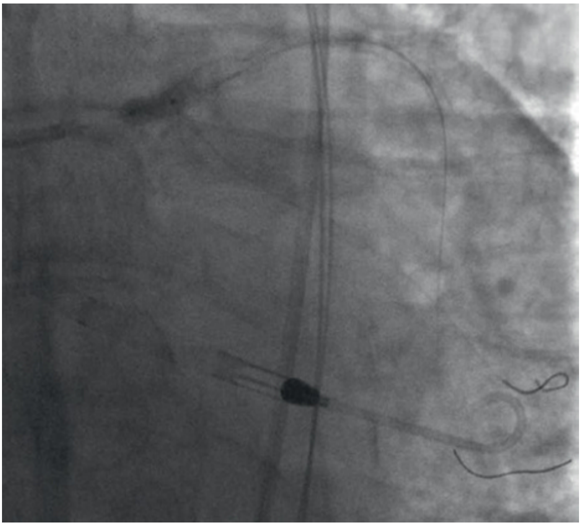


Figure 17.5 Proximal optimisation of the proximal main vessel.

pinky fingers. The hub of the microcatheter is then rotated three times clockwise, followed by three counterclockwise rotations, as the catheter is advanced with persistent forward pressure from the left hand. Once the microcatheter is successfully delivered to the distal vessel, it is exchanged for a Viper wire (Cardiovascular Systems Inc., Saint Paul, MN, USA) or Rota wire (Asahi Intecc, Nagoya, Japan) for potential atherectomy. Laser atherectomy devices offer the advantage of being usable over any wire, making them a potential solution for lesions resistant

Table 17.2 **Strategies for balloon uncrossable vessel**

• **Augmented catheter support**	
	Larger guide with more supportive shape
	Long arterial sheaths
	Deep engagement
	Guide catheter extension
	Anchor wire
	Buddy wire
	Anchor balloon: side branch, distal target vessel or subintimal at or below lesion site
• **Lesion modification**	
	Appropriate small balloon (1.20–1.5 mm) manipulation
	Wedgies and grenadoplasty (intentional balloon rupture)
	Microcatheters: Tornus, Corsair, Carvel, Finecross, Turnpike
	Excimer laser: ablative and acoustic energy
	Rotational atherectomy
	Seesaw balloon-wire cutting technique
	Multi-wire plaque crushing technique
	Crowbar effect
	Retrograde approach

to microcatheter exchanges. In cases where, despite all efforts, the microcatheter cannot be advanced to the distal vessel, the microcatheter is positioned as far as possible, and the remaining vessel is directly wired with a Viper wire or Rota wire, allowing for subsequent atherectomy.

COMPLICATIONS

If you have not had complications during complex high-risk interventions, you have not done enough of them. We, in our **5-year** journey of doing CHIP cases, have seen a wide range of complications – both coronary and vascular.

Pericardial Effusion

Pericardial effusion during coronary intervention can range from small, self-limiting instances to severe tamponade with hemodynamic compromise and cardiac arrest. Common causes include coronary perforation due to oversized balloons, atherectomy, or stiff wires. This complication should be suspected whenever unexplained hypotension occurs or when an LVAD suction alarm is triggered. The use of a Swan-Ganz catheter and monitoring LVEDP via the Impella console during the procedure facilitates early detection. In some cases, pericardial effusion may not accumulate until several hours after the procedure. Previous open-heart surgery and pericardial scarring can provide significant protection against cardiac tamponade in the event of coronary perforation. For monitoring a minor or contained coronary perforation, a novel approach involves injecting Definity contrast (Perflutren Lipid Microsphere Injectable Suspension, Lantheus Medical Imaging, North Billerica, MA, USA) through the guide; if the contrast appears in the pericardium, this indicates active extravasation. This technique is also valuable for assessing the risk of reaccumulation following drainage of a pericardial effusion (Videos 17.10 to 17.15).

Video 17.10 Coronary perforation after orbital atherectomy in a patient with previous CABG.

Video 17.11 Fluoroscopic monitoring of the pericardial effusion. The extravasated contrast from coronary perforation is seen at the bottom. The persistence suggests that there is no active bleeding into the pericardial sac causing dilution of the contrast.

Video 17.12 After successful completion of complex coronary intervention, the patient develops profound hypotension with suction alarm from the Impella.

Video 17.13 After obtaining pericardial access with a needle under echocardiographic guidance, agitated saline is injected to confirm the position in the pericardial cavity.

Video 17.14 Broken Viper wire: during atherectomy, it is imperative that the device does not come in contact with the radiopaque portion of the wire. This may be complicated by disruption of the wire as in this case.

Video 17.15 Dislodged atherectomy crown in circumflex artery. (Dislodgement of the rotablator burr or orbital atherectomy crown is an unusual complication.)

In the above case, the circumflex artery was double wired and the crown was released from the calcified plaque using angioplasty and intravascular lithotripsy. The Viper wire (Cardiovascular Systems Inc, St Paul, MN) is a 0.09 inch wire and distal end is 0.014 inch. The atherectomy crown lumen is only 0.09 inch. The broken crown was locked between the teleport support catheter proximally and 009-014 interface and pulled out with the wire.

Catastrophic Left Main Dissection

An elderly male patient underwent a planned high-risk multivessel percutaneous coronary intervention. A 7-F EBU 3.5 guide catheter was used to engage the LM coronary artery, and the LAD artery was successfully wired. During IVUS imaging, the patient developed hemodynamically unstable ventricular tachycardia, progressing to cardiac arrest. Subsequent coronary angiography revealed a dissection of the LM coronary artery with compromised flow into the LAD, likely precipitated by the guide catheter. Cardiopulmonary resuscitation was initiated, contralateral arterial access was obtained, MCS was deployed, and stenting of the LM and LAD arteries was performed. This complication underscores the critical importance of careful manipulation of larger, stiffer guide catheters, ensuring coaxial alignment with the coronary ostium, continuous waveform monitoring from the guide tip, and early preparedness for catastrophic events – including immediate availability of alternate access for MCS (Video 17.16).

Video 17.16 Left main dissection.

No-reflow

No-reflow is the most common complication in our lab after orbital atherectomy. The common predictors are long segment diffuse disease, long or repeated runs of atherectomy, and small vessel, severe tortuosity, high-speed orbital atherectomy. We have had significant success in reducing no-reflow by using intracoronary administration of radial cocktail prior to atherectomy (unfractioned heparin, nitroglycerin, and verapamil). If there is no-reflow, we put a teleport catheter and inject adenosine and nitroglycerin flush till reflow is established (Video 17.17).

Video 17.17 No-reflow.

Iliac Perforation

This patient underwent a successful high-risk PCI with MCS. The support device was weaned and explanted without complication. The large-bore left femoral access site was closed using a MANTA closure device, and angiography confirmed adequate hemostasis. The right femoral artery (7-F) access was closed with a Celt closure device.

Before the patient was taken off the table, the patient developed shock that was unresponsive to intravenous fluids and multiple vasopressors. The left femoral artery was reaccessed distal to the previous arteriotomy using a micropuncture technique, and angiography confirmed an intact seal. Due to worsening hemodynamic instability, this access was upsized to accommodate a large-bore sheath, and an Impella device was inserted into the LV. Through the same Impella access site, a second 7-F sheath was placed into the left femoral artery. Coronary angiography ruled out coronary perforation. Right heart catheterization and left ventricular diastolic pressure measurements were not consistent with tamponade and instead suggested hypovolemic shock. Thoracic and abdominal aortic angiography revealed no evidence of contrast extravasation.

However, angiography of the right iliac artery identified a large perforation associated with the closure device. A massive transfusion protocol was initiated. The right iliofemoral artery was accessed via an up-and-over sheath from the left side. Temporary hemostasis was achieved with balloon tamponade, followed by definitive repair using a covered stent.

This case underscores the potential for catastrophic complications at any stage of high-risk PCI. It also emphasizes the critical importance of invasive evaluation in cases of acute shock, as there is often insufficient time for noninvasive assessments such as imaging or laboratory tests. In this case, coronary angiography excluded coronary injury; right heart catheterization ruled out tamponade and cardiogenic shock; and aortography excluded large-vessel trauma. Timely, stepwise diagnostic assessment and intervention ultimately prevented a fatal outcome from this unexpected and life-threatening complication (Video 17.18).

Video 17.18 Iliac perforation.

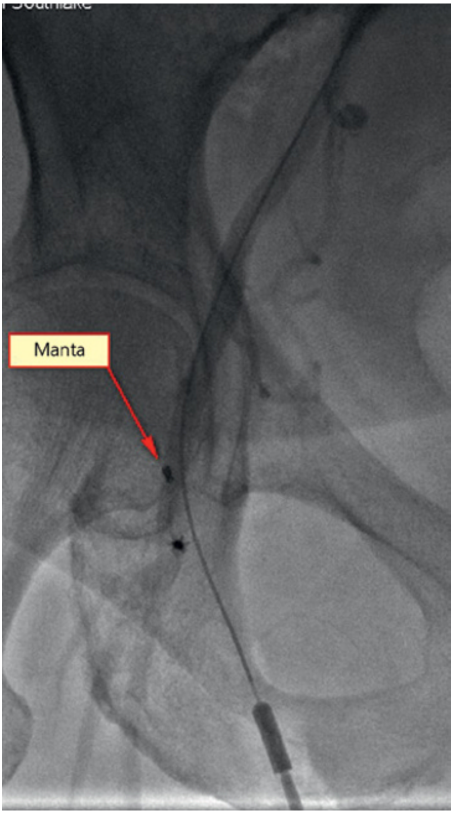


Figure 17.6 Radio opaque Manta marker is seen at the lower quadrant of the right femoral head on fluoroscopy.

Late Iatrogenic Intravascular Migration of Manta

Reaccessing an artery previously closed with the MANTA large-bore vascular closure device should generally be avoided within 2.5 cm above or below the original arteriotomy site for at least 6 months. In this case, the patient had a prior large-bore femoral access closed with the MANTA device. After a 6-month interval, the artery was reaccessed under fluoroscopic guidance using micropuncture technique, with all standard precautions observed. The radiopaque marker of the prior MANTA device was identified fluoroscopically and mentally referenced in relation to bony landmarks (Figure 17.6).

Following insertion of the micropuncture catheter, fluoroscopic assessment revealed superior displacement of the radiopaque MANTA marker, raising suspicion of intravascular migration of closure material. This finding was subsequently confirmed by angiography (Figure 17.7). Contralateral femoral access was obtained, and the iliofemoral system was traversed with a guidewire. A covered stent was deployed to exclude the migrated material, restoring normal flow through the iliac and femoral arteries (Figure 17.8).

Early recognition of this potentially catastrophic complication prevented no-reflow and thrombosis of the iliofemoral system. Intravascular migration of MANTA closure components should be considered while reaccessing an artery with a history of large-bore closure using this device. The risk is elevated when reaccess occurs within 2.5 cm of the original closure site and within 6 months of the initial procedure. Careful fluoroscopic localization of the MANTA marker in relation to bony landmarks is critical for early detection and appropriate management of this complication.

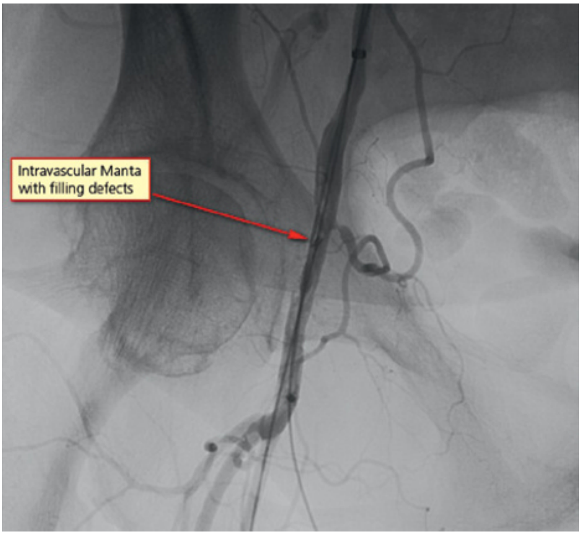


Figure 17.7 Following insertion of the micro-puncture sheath, the radiopaque Manta marker appears to have migrated superiorly toward the right pelvic brim. This has resulted in intravascular displacement of the Manta closure components, evidenced by filling defects on angiography. The situation poses a significant risk for iliofemoral thrombosis, acute vessel occlusion, and acute limb ischemia—each constituting a vascular emergency.

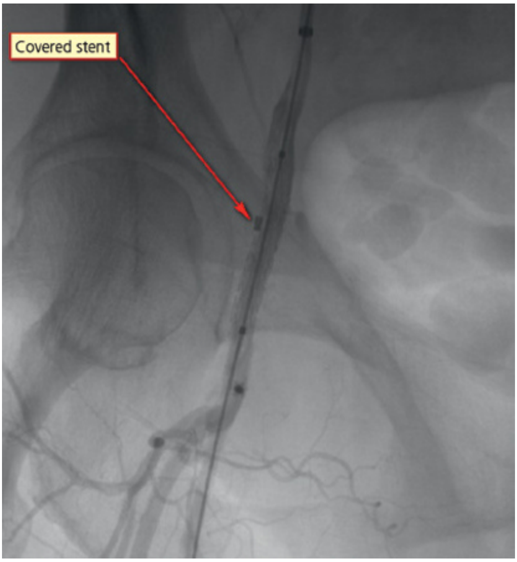


Figure 17.8 Right iliofemoral artery was wired from a contralateral sheath and a covered stent was deployed to exclude the migrated intravascular elements of the old Manta closure device and establish normal circulation in the right iliofemoral system.

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CHAPTER 18

Coronary Atherectomy

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

The presence of coronary artery calcification is a marker of advanced atherosclerosis. Heavily calcified lesions increase the complexity of percutaneous coronary intervention (PCI) because they are (1) difficult to predilate; (2) prone to dissection during plain old balloon angioplasty (POBA), especially if high-pressure balloon inflations are performed; and (3) difficult to have a stent delivered into and limit adequate stent expansion. These factors may explain the increased risk of death, myocardial infarction, target vessel revascularization, and stent thrombosis in PCI for heavily calcified lesions.

In order to increase the short- and long-term success of PCI of complex or severely calcified lesions, lesion preparation with atherectomy is the best strategy. However, this is a more involved procedure and more technically challenging compared to conventional POBA and stenting. Further, periprocedural complications can be catastrophic, so appropriate patient selection and meticulous technique are needed in order to minimize the risk.

IMAGING

Various imaging modalities are available for the quantification of coronary artery calcification to help determine the need for coronary atherectomy.

Fluoroscopy and Angiography

Fluoroscopy and angiography may provide significant diagnostic yield but are limited in their ability to identify and quantify calcium distribution (Figure 18.1). This can be secondary to the fact that hazy angiographic images may represent irregular plaque morphology, distorted lumen, thrombus, or dissection [1–3]. Although coronary artery calcification can be visualized on fluoroscopy, it is not possible to distinguish whether it is superficial or if it severely compromises the lumen diameter [4]. Therefore, the need for lesion preparation with coronary atherectomy can be difficult to determine with angiography alone.

Intravascular Ultrasound

Intravascular ultrasound (IVUS) is superior to angiography alone in evaluating coronary artery calcification [5]. IVUS gives a unique view of the coronary vessel wall, allowing for significantly improved delineation of the extent, composition, morphology, and distribution of plaque throughout the artery, and thereby assisting the operator to determine whether plaque modification is indicated (Figure 18.2) [6, 7]. While dense calcium is hyperechoic, or bright, on ultrasound, soft or superficial plaque appears less echo-dense. Although IVUS cannot penetrate the calcium itself to visualize depth, it is useful in quantification of the arc and

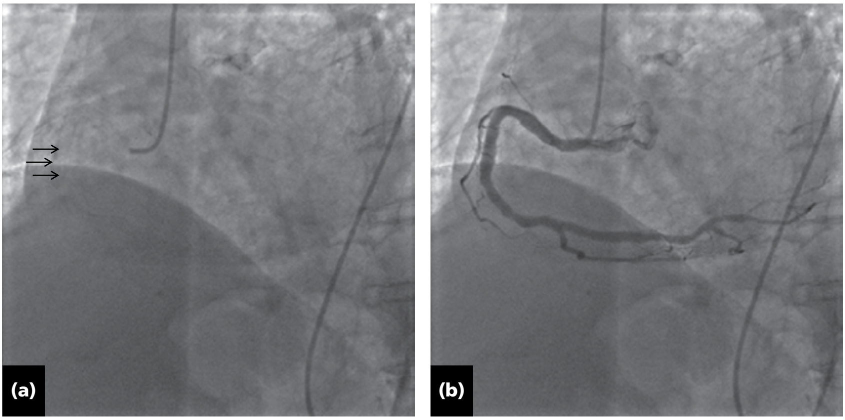

Figure 18.1 (a) Fluoroscopy demonstrates a heavily calcified right coronary artery (arrows). (b). Coronary angiography demonstrates mild luminal irregularities despite severe coronary artery calcification.

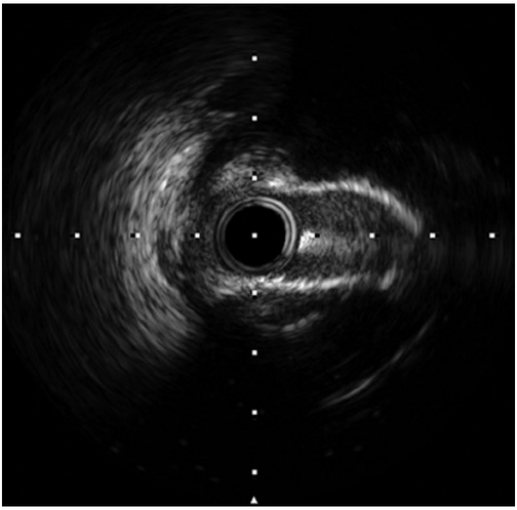

Figure 18.2 IVUS shows severe coronary artery calcification.

length of calcium deposition. Coronary atherectomy should be considered when the arc of calcium is ≥270°. The limitations of IVUS include the cost, prolonged procedural time, and increased risk, including spasm and dissection.

WARNING

Prevention of Spasm and Air Embolism

Intracoronary administration of nitroglycerin can decrease the risk of coronary spasm. Prior to insertion into the guide, the IVUS catheter should be vigorously flushed to remove air from the catheter. The IVUS catheter should not be flushed while in the guide due to the risk of air embolism.

Optical Coherence Tomography

Optical coherence tomography (OCT) accurately characterizes the extent and morphology of coronary artery calcification due to its ability to limit artifact and use fiberoptic technology, which increases the resolution nearly 10-fold compared to IVUS [8–10]. Similar to IVUS, OCT is used to optimize stent deployment by evaluating stent expansion and apposition [11].

The two types of OCT currently used are time-domain OCT (TD-OCT) and Fourier-domain OCT (FD-OCT). These devices differ in their specifications for axial scanning, lines/frame, and pull-back speed, as well as resolution and tissue penetration. With a central wavelength of ~1300 nm, OCT typically penetrates 1–2 mm as compared to 4–8 mm with IVUS [11]. Therefore, OCT has less far-field visualization compared with IVUS and is thus inferior in delineating the reference vessel diameter. The radiographic evaluation of stent apposition and stent-strut coverage in the acute setting is considered a surrogate for stent thrombosis. In intermediate (6 months) or long-term (>1 year) follow-up, the method of identifying the risk of stent thrombosis is the presence of neointimal hyperplasia. In this methodology, OCT is superior to IVUS in the identification of neointimal hyperplasia.

Like IVUS, OCT increases the cost and time of the PCI. Because there is strong attenuation of light by blood, TD-OCT requires removal of blood during OCT examination to prevent scattering of light by red blood cells. This is avoided by first preventing blood flow via balloon occlusion of the vessel with subsequent saline irrigation [10]. Newer FD-OCT technology significantly improves scanning time with accelerated pull-back speeds that allow for bolus injection of contrast that provides a blood-free location, obviating the need for balloon occlusion [11]. In head-to-head comparisons with IVUS, OCT had similar complication rates [12–14].

INDICATIONS FOR ATHERECTOMY

Coronary atherectomy is an invaluable tool that should be reserved for selected patients with coronary artery calcification, especially in cases where the likelihood of stent delivery and optimal expansion is low. The American College of Cardiology Foundation/American Heart Association and Society for Cardiovascular Angiography and Interventions guideline for PCI provides a class IIa recommendation for rotational atherectomy (RA) use in fibrotic or heavily calcified lesions that might not be crossed by a balloon catheter or adequately dilated before stent implantation (level of evidence C) [15]. The decision to modify severely calcified plaque must be weighed against the potential risk for complications, especially when confronted with unfavorable anatomy such as tortuous vessels or long diffuse lesions, and in patients with poor left ventricular function. Data do not support the routine use of atherectomy [16–19]. The ultimate determination is based on the degree of coronary calcium: the benefits of atherectomy are diminished when minimal calcium is present (Figure 18.3).

SHARP THINKING

When is Atherectomy Needed?

IVUS and OCT can help determine the severity of coronary artery calcification. Atherectomy should be used if the arc of calcium is ≥270°. If IVUS is not available, balloon inflation at nominal pressure or at least 16 atm should be performed to determine if the balloon can be fully expanded. This is important in vessel preparation for a bioreabsorbable scaffold. If the balloon does not fully expand, coronary atherectomy is needed. If a dissection occurs after POBA, RA can still be performed by an experienced operator (please see the following technical tips) [21, 22].

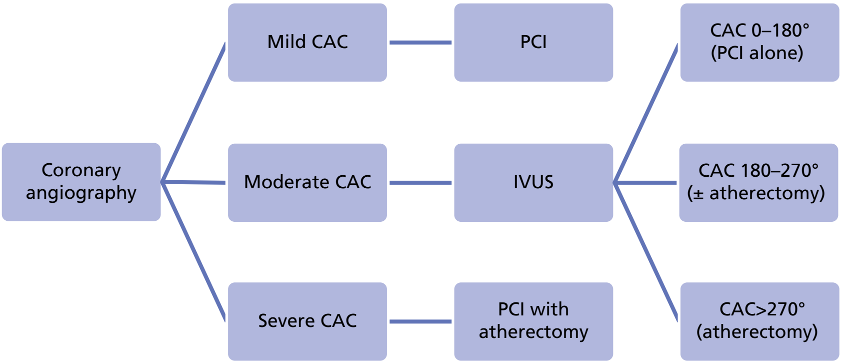

Figure 18.3 Treatment algorithm for atherectomy. CAC = coronary artery calcification; PCI = percutaneous coronary intervention; IVUS = intravascular ultrasound. Source: Adapted from [20].

Tips and Tricks

** **Rotational atherectomy in patients with small dissection** RA can be performed in vessels with dissection from prior balloon angioplasty. A ROTAWire Extra Support (Boston Scientific, Marlborough, MA, USA) and a small 0.125-inch burr are recommended to minimize the risk of further dissection or burr trapping. Atherectomy should be performed at a higher rpm of 180 000. This should provide sufficient plaque modification for stent delivery.

** **Contraindications for atherectomy** Relative contraindications to rotational and orbital atherectomy (OA) include saphenous vein graft lesions, presence of thrombus, and coronary dissection. For experienced operators, there are no contraindications. Other relative contraindications include the lack of cardiothoracic surgery availability, severe three-vessel or unprotected left main disease, severe left ventricular dysfunction, lesions longer than 25 mm, and lesion angulation >45° [23]. The use of atherectomy with the simultaneous presence of at least one of these high-risk characteristics has been associated with both increased slow flow and periprocedural non-Q-wave myocardial infarction [24].

ROTATIONAL ATHERECTOMY

Rotational atherectomy, which was first developed in the late 1980s, consists of a rapidly rotating burr coated with 2000–3000 microscopic diamond chips, which modifies calcified plaque and changes vessel compliance, thereby facilitating stent delivery and expansion (Figure 18.4) [25]. Each diamond chip is 20 μm in diameter, with only 5 μm extending beyond the nickel coating [18, 26]. Other components of the device include the console, drive shaft, and turbine, with the turbine being activated via a foot pedal. The burr, which is bonded to the drive shaft, has sizes ranging from 1.25 mm to 2.5 mm. A 0.009-inch ROTAWire is required to perform RA.

The mechanism of action is differential cutting, whereby the burr ablates inelastic tissue (i.e. calcium and fibrous tissue), whereas the elastic property of healthy tissue deflects the edges of the diamond microchips (Figure 18.5) [25]. The combination of both differential cutting and longitudinal friction via changes in circumferential direction helps the burr advance through difficult vessels and lesions. As it ablates, plaque debris passes through the coronary microvasculature and is subsequently cleared by the reticuloendothelial system [18, 23]. The burr:artery ratio is 0.5, as the intent of RA is plaque modification rather than debulking.

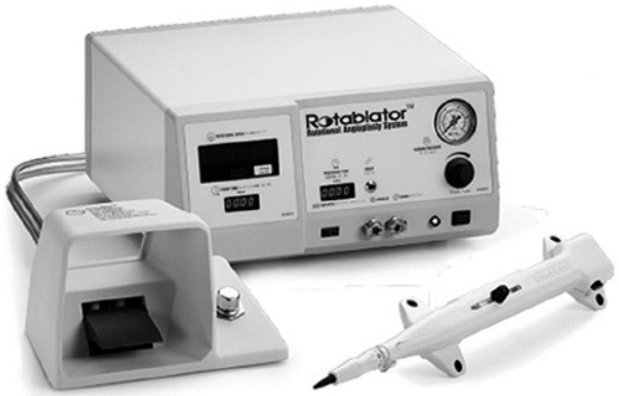

Figure 18.4 The rotational atherectomy system includes the console, foot pedal, and RotaLink Plus advancer and burr. Source: Boston Scientific Corporation / https://www.bostonscientific.com/en-US/products/atherectomy-systems/rotablator-rotational-atherectomy-system1.html / Last access on May 06 2025.

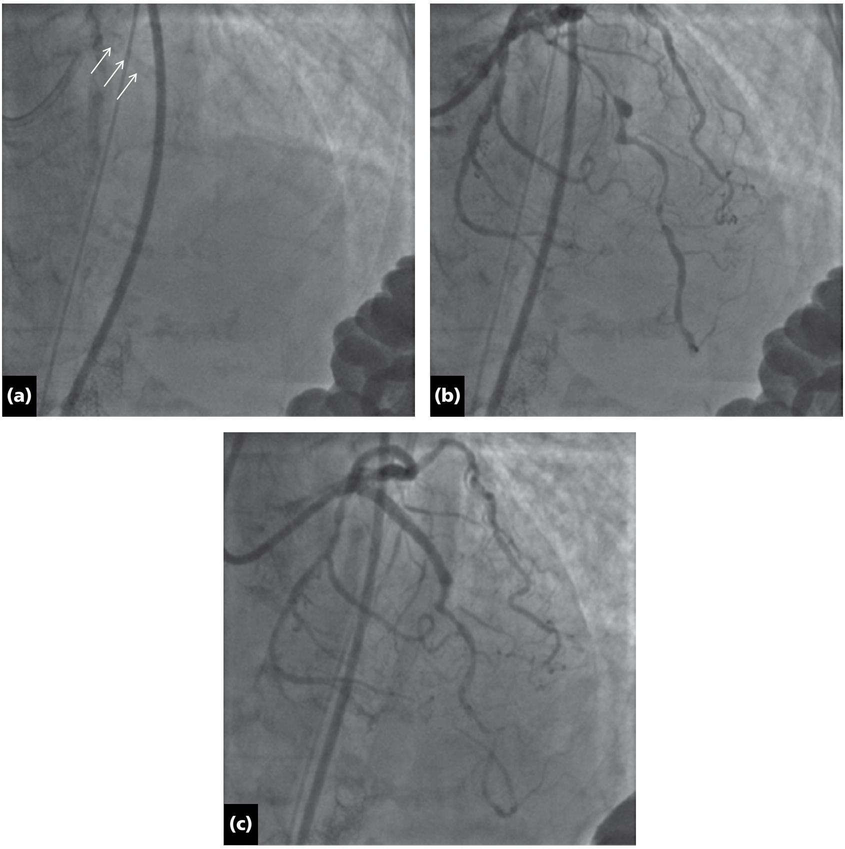

Figure 18.5 (a) Fluoroscopy shows severe coronary artery calcification of the left main coronary artery and left anterior descending artery (arrows). (b) Coronary angiography demonstrates a severe stenosis of the left anterior descending artery. (c) Final angiography after rotational atherectomy with a 1.75-mm burr followed by stenting shows an optimally expanded stent.

Technique

Wiring A workhorse wire should be used to traverse the lesion, followed by exchange for the ROTAWire through an over-the-wire (OTW) balloon or any other wire exchange catheter, because the Rota-wire is often difficult to pass through diffusely diseased and calcified arteries. If the Rota-wire is inadvertently pulled back while the drive shaft is on it, the Rota-wire can be advanced by activating Dynaglide, overriding the brake, and pushing the wire forward. If there is difficulty in delivering the burr to the lesion, either due to proximal tortuosity or obstruction from calcium spicules or a proximal stent, gently tap on the Dynaglide.

Advancing the burr After advancing the burr proximal to the lesion but before ablating the lesion, maneuvers to take the slack out of the system to minimize the chance of the burr jumping forward include (1) gently pulling back on the drive shaft and taking the stored tension from advancing the shaft and (2) loosening the advancer knob and moving it back and forward. A "single operator" technique can be used to advance the drive shaft to the lesion in situations where a skilled assistant is not available to hold the ROTAWire [20].

Ablation pass The burr should be advanced with a slow (1-mm/s) pecking motion with a 2-s contact time and 1-s withdrawal time to allow blood flow and cooling. Each pass of atherectomy should be kept to a short duration (<15–20 s) to minimize excessive friction that can cause vessel injury, platelet activation, release of large debris particles [23], and heat generation, which may increase restenosis. Deceleration of the burr more than 5000 rpm indicates that the burr should be advanced more slowly or pulled back.

RotaFlush Avoid the addition of vasodilators such as nitroglycerin and verapamil to the rota-flush solution to decrease the risk of periprocedural hypotension [27] and bradycardia. A commonly accepted flush would include RotaGlide™ (Boston Scientific, Marlborough, MA)c) where available, 5000 units of heparin, and 5 mg of nicardipine. Constant flushing with normal saline during each pass can decrease the viscosity of blood by decreasing heat generation.

Pacemaker The insertion of a temporary pacemaker should be considered if the patient has baseline bradycardia or bundle branch block and certain lesion types (i.e. long, diffuse lesions in the right coronary artery [RCA] or dominant left circumflex artery). If a temporary pacemaker is not inserted, the nurse should have atropine readily available for immediate administration. This can also be given at the time of platforming so it can circulate by the time of ablation.

SHARP THINKING

When to Skip Temporary Pacemakers

There are risks associated with temporary pacemakers, including right ventricular perforation causing tamponade, especially if glycoprotein IIb/IIIa inhibitors and non-balloon-tipped pacemaker leads are used. Bradycardia usually resolves with continued RA; therefore, the use of a temporary pacemaker can be skipped in cases of short lesions and moderately calcified arteries. For prevention, atropine or an intravenous (IV) bolus of aminophylline 5 mg/kg can be given (however, beware of urinary retention in male patients). In case of adenosine-mediated bradycardia, use aminophylline as a 5-mg/kg IV bolus.

Hypotension

The floating nurse in the cardiac catheterization laboratory should have phenylephrine readily available to administer immediately if severe hypotension develops; phenylephrine should be administered before rotablation if baseline blood pressure is low. Patients with left ventricular systolic dysfunction should be evaluated for a hemodynamic support device [24].

WARNING

Atherectomy of Ostial RCA

Be aware that the lesion and calcification reflect disease of the aortic wall, which is thick, less distensible, and at risk for recoil. The impact of a smaller-sized burr can be increased in ostial lesions with the use of a ROTAWire Extra Support to anchor in the vessel and bias the burr superiorly and inferiorly while treating the ostium.

Use of a cutting balloon in ostial lesions can result in aortic dissection because of the risk of hydraulic dissection with subsequent injections. Aortic dissection can be treated medically if it is less than 10 cm in length.

ORBITAL ATHERECTOMY

The Diamondback 360® Peripheral Orbital Atherectomy System (Cardiovascular Systems, St Paul, MN) is the only FDA-approved device for the treatment of severely calcified coronary lesions (Figure 18.6). It consists of a 1.25-mm crown that is eccentric in shape and has microscopic diamond chips that modify calcified plaque and change vessel compliance, thereby facilitating stent delivery and expansion. A specialized wire (ViperWire) (Cardiovascular Systems, St Paul, MN)) is required to perform OA (Figure 18.7).

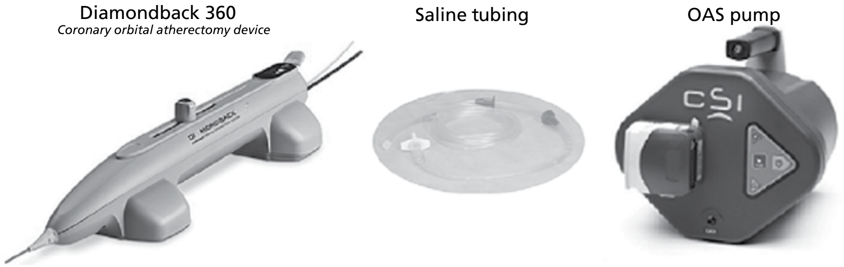

Figure 18.6 The orbital atherectomy system includes the advancer, saline tubing, and pump. Reproduced with the permission of Cardiovascular Systems, Inc., Saint Paul, MN, USA.

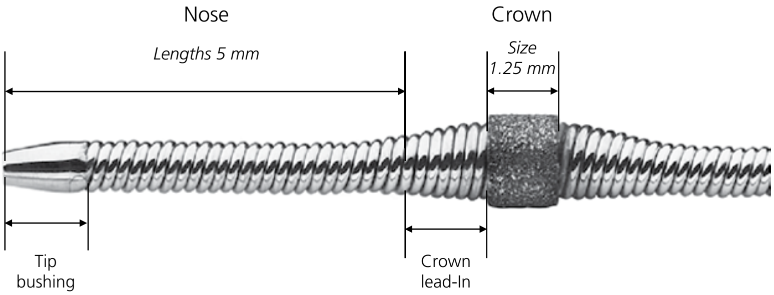

Figure 18.7 The diamond-coated crown is available in diameters as listed in Table 18.1. Each crown size has a specific nose length. Reproduced with the permission of Cardiovascular Systems, Inc., Saint Paul, MN, USA.

SHARP THINKING

Differences and Similarities between OA and RA

There are several theoretical benefits of OA over RA. The mechanism of action of OA is bidirectional differential sanding, in which ablation occurs while the crown is advanced and pulled back while healthy elastic tissue flexes away, minimizing damage to the vessel, whereas RA only ablates during burr advancement (Figure 18.8). A unique feature of OA is the ability of the elliptical motion to increase in size with greater speeds due to an increase in centrifugal force, resulting in a greater lumen diameter while lessening both procedure time and the need for upsizing catheters [28]. OA requires insertion only once with the ability to go from low speed (80 000 rpm) to high speed (120 000 rpm) when the reference vessel diameter is generally ≥3 mm, whereas RA requires removal and reinsertion of larger burrs to achieve adequate plaque modification. OA uses a larger-diameter guidewire (0.012 inch) compared with the Rota-wire (0.009 inch), which is easier to torque and advance across lesions. The eccentrically mounted crown and its ability to be only in contact with one portion of the vessel at a time allow for continued blood flow through the vessel without any obstruction in an already diseased blood vessel. The continuous clearance of debris allows for continuous flushing downstream of particles as well as decreasing device-generated friction and heat. OA is compatible with a 6-Fr guiding catheter, whereas larger guiding catheters are needed for RA burrs ≥1.75 mm.

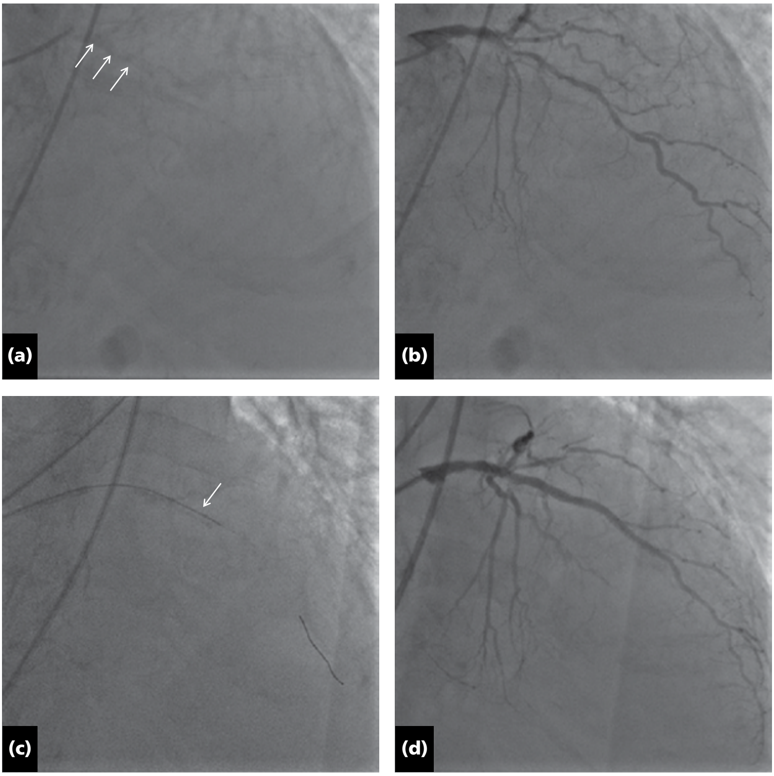

Figure 18.8 (a) Fluoroscopy demonstrates severe coronary artery calcification of the left main coronary artery and left anterior descending artery (arrows). (b) Coronary angiography demonstrates a severe stenosis of the left anterior descending artery. (c) Orbital atherectomy (arrow) was performed to modify the severely calcified plaque. (d) Final angiography demonstrates excellent angiographic results.

Tips and Tricks

1. OA and RA share many of the same tips and tricks.
2. A high-pitched tone will be heard when the crown makes contact with the calcified plaque. Passes with OA should be performed until the high-pitched tone decreases.
3. If the crown does not advance through a very resistant lesion, the operator should not push aggressively due to the potential of the crown to jump forward.
4. After starting with low speed, high speed should be considered if the vessel diameter is ≥3 mm.
5. For ostial lesions, the crown should be activated after it is distal to the lesion and then pulled back.
6. The ViperWire is sufficiently supportive and can be used to advance balloons and stents. Cutting the wire with a pair of scissors to approximate a regular length (160 cm) may make it more convenient to advance rapid-exchange catheters.
7. A GuideLiner® catheter can facilitate the delivery of OA through tortuous or angulated vessels.

Getting the burr to where it needs to go If the wire support catheter does not cross critical stenosis, either predilate with a small balloon or remove the crossing wire with a "dottering" motion and immediately advance the rotawire (a floppy rotawire might be better than an extra-support rotawire).

In order to get the burr down to a distal lesion, advance the burr as far distally as possible and move the "advancer (of burr)" backward while advancing the rotablator sheath forward. The burr should stay in the same position in the coronary artery as the sheath is advanced and the advancer withdrawn. (**Beware:** When you start atherectomy, the burr will jump backward first.)

EXCIMER LASER ATHERECTOMY

Laser atherectomy (LA) utilizes fiberoptic technology to deliver high-energy light emission to alter or disintegrate the plaque without directly affecting the surrounding healthy tissue (Figure 18.9) [25]. Although not as effective for severe coronary artery calcification as RA or OA, laser atherectomy uses ultraviolet (UV) pulses to debulk complex coronary lesions. These lesions include moderately calcified plaque, fibrous tissue, atheroma, and thrombus. Several catheter sizes are available, and catheter size selection depends on (1) the amount of fibers, (2) different wavelengths of lasers, (3) the manner in which the light is transmitted, and (4) the power of the laser.

The use of continuous versus pulsed-wave laser affects the degree to which the laser is able to affect the plaque. One of the major limitations of initial LA usage was the constant power output that led to significant thermal damage and subsequent thrombosis, vasospasm, and high restenosis rates [29–33]. For higher tissue depth, the wavelength must be greater, typically in the near-infrared region [34]. UV light, with its shorter wavelength, has a direct photochemical lytic effect rather than a thermal effect, decreasing damage to the vessel wall. The current model of excimer LA delivers high energy in a pulsed fashion, breaking chemical bonds in the tissue without damaging surrounding material or causing heat damage [34]. Another benefit of excimer LA is the ability to vaporize concomitant thrombi, thus decreasing the risk of platelet aggregation during plaque modification [35].

Before the introduction of advanced laser catheters and technique refinement, the perforation rate was 3% of procedures during the initial clinical evaluation period in the early 1990s [16]. In the late 1990s, changes in laser technique included continuous infusion of saline at the site of ablation. In addition, smaller catheters with optimally spaced fibers and increased laser operating parameters were developed. Appropriately sized catheters, in addition to increased ablation efficiency, led to a lower incidence of dissection and perforation. The incidence of laser-induced perforations in a cohort of 1865 patients ranged from 0% to 2.0%,

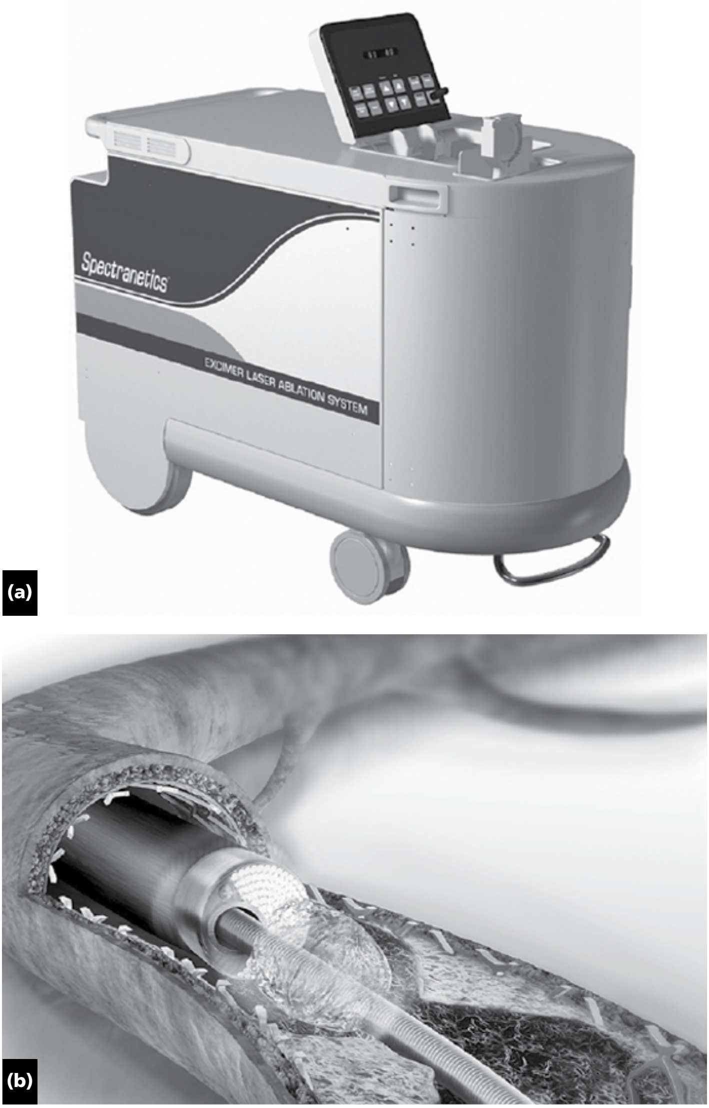

Figure 18.9 (a) Laser atherectomy console. (b) Laser atherectomy catheter uses ultraviolet pulses to debulk complex coronary lesions, including moderately calcified plaque, fibrous tissue, atheroma, and thrombus. (a,b) Courtesy of Royal Philips.

with a calculated weighted average of 0.3%. A meta-analysis of 9568 unselected patients undergoing PCI with balloon and stenting from a similar period (2001–2008) reported a perforation rate of 0.59% [36]. It is noteworthy that whereas the stent analysis was conducted on unselected patients with varying lesion complexity, coronary LA is typically used in complex lesion subsets. In comparison, the perforation rate in complex chronic total occlusion procedures was 2.9% in a large meta-analysis of 18 061 patients and has been reported as high as

13.6% in a large contemporary chronic total occlusion registry [37, 38]. Therefore, the safety profile of coronary LA compares favorably to current PCI techniques.

Currently, LA is indicated for use in long lesions (>20 mm), moderately calcified lesions, chronic total occlusions, undilatable lesions, ostial lesions, saphenous vein grafts, and in-stent restenosis, and it has unique attributes to facilitate treatment of thrombus-containing lesions. LA is compatible with any standard wire, including dedicated chronic total occlusion wires. In fact, in a series of patients with Rotawire-resistant lesions that were subsequently crossed with coronary LA and then followed with RA for additional debulking of severe calcium, the combined treatment paradigm resulted in 91% crossing success and facilitated stent delivery [39].

Technique

During use, the operator has control of two specific factors: the frequency of the waves administered and the amount of energy, also known as fluence [34]. Depending on the specific lesion, the operator can adjust these factors to be more efficient in plaque modification. In practice, there is a fine balance between the pulse repetition rate and the fluence administered to help minimize thermal effects during the procedure [40].

A frequency:fluency of 40:40 is typically the initial setting. The settings can be increased after several passes have been made. Effective plaque removal via slow advancement of the catheter (1 mm/s) creates both a smoother and larger vessel diameter.

WARNING

Dissections

LA should not be performed while injecting contrast media because both contrast and blood have high absorption of the emission light, creating a risk of dissection and perforation [41, 42]. However, laser with contrast injection is used for in-stent restenosis with multiple layers of stents for deep wall modification to allow expansion of underdeployed stents.

COMPLICATIONS

Vascular Complications

The risk of coronary vasospasm can be reduced by pretreatment with intracoronary nitroglycerin. A smaller burr:artery ratio (<0.7) may reduce angiographic complications compared with aggressive burr sizing (>0.7) [43, 44].

Coronary perforation requires immediate treatment to prevent hemodynamic collapse from cardiac tamponade and death. Slow and cautious movement of the atherectomy device to prevent significant decelerations, as well as a small burr:artery ratio, can decrease the risk of this catastrophic complication. Atherectomy in tortuous and angulated vessels should also be avoided.

Tips and Tricks in Case of Coronary Perforation

Recognizing tamponade Tamponade from perforation will manifest with hypotension. Diagnosis can be made by many different methodologies, including arterial waveform of pulsus paradoxus and equalized right heart pressures (elevated right atrium, right ventricular end diastolic pressure, pulmonary arterial diastolic pressure, and pulmonary capillary wedge pressures). The cardiac silhouette may be straightened, and there may be a halo sign. With tamponade there may be compression of the coronary sinus with decreased opacification.

Management Immediately tamponade the perforated area with an OTW balloon for 3–12 min. This time could be limited because of pain, arrhythmias, or hemodynamic instability. In case of chest pain, use sedation. If bleeding continues after prolonged balloon inflation, consider reversing heparin with protamine. Covered stents or coils can be used to control bleeding. The operator should know where the covered stents are stored and know how to perform pericardiocentesis before undertaking atherectomy.

Coronary dissection The risk of dissection can be minimized by careful technique using the same level of caution to prevent perforation. The vast majority of dissections can be successfully treated with stenting without clinical sequelae.

Prevention of stroke Larger catheters and frequent catheter exchanges increase the risk of cerebrovascular events, possibly due to arterial debris from calcified vessels that embolizes to the cerebral vasculature [45].

Slow/no reflow Slow flow, defined as reduced coronary flow (thrombolysis in myocardial infarction [TIMI] grade 2), is due to a combination of showering of atherosclerotic debris with subsequent thrombotic phenomena and platelet activation in the absence of dissection, stenosis, or thrombus. No reflow refers to the presence of TIMI 0–1 in the coronary vasculature without any obvious cause. Periprocedural ischemia and myocardial infarction with release of cardiac biomarkers can occur due to slow/no reflow. Strategies to minimize the risk of slow/no reflow include prophylactic intracoronary administration of vasodilatory agents and appropriate device sizing, as well as slow and short duration passes (Table 18.1).

Table 18.1 **Prevention and Treatment Strategies for Slow/No Reflow During Atherectomy**

Mechanism	**Therapeutic strategy**
Atheromatous debris embolus	Small burr sizing Short duration of ablation Avoidance of significant deceleration
Platelet activation and aggregation	Optimal antiplatelet therapy Bailout glycoprotein IIb/IIIa inhibitor
Microcirculatory vasospasm	Vasodilatory agents: Adenosine Nicardipine Nitroprusside
Neurohumoral reflex bradycardia	Atropine Aminophylline bolus
Intraprocedural hypotension	Vasopressor: Phenylephrine for immediate response Dopamine or norepinephrine if sustained Intra-aortic balloon pump

Source: Adapted from [23].

Burr entrapment Burr entrapment is a rare phenomenon that has the potential to lead to serious complications. Ablation only occurs while the RA burr is advanced, as only the distal half of the burr has diamond chips, while the proximal half of the burr does not. Consequently, if the proximal portion of the burr passes an incompletely ablated vessel, it could become entrapped in the calcified lesion because of the inability to perform retrograde ablation. Strategies to remove the entrapped burr include deep intubation with the guiding catheter or balloon angioplasty at the location of burr entrapment [46]. Inability to remove the burr or shaft fracture necessitates emergent surgery.

Tips and Tricks

****Prevent burr entrapment** Various techniques can decrease the risk of burr entrapment. Smaller burrs may reduce the potential for burr entrapment due to their mobility. However, the 1.25-mm rotablator burr may be associated with higher risk because of the shape of the burr. Short duration of passes using a "pecking" motion (gradual and intermittent advancement of the burr) rather than aggressive advancement is the preferred technique to avoid burr deceleration and stalling within the lesion [23]. High speed (>170 000 rpm) may allow the burr to cross the calcified lesion more easily. Despite optimal technique, burr entrapment can still occur. Utilization of visual, auditory, and tactile senses can help decrease the incidence of complications. Poor advancement of the burr on fluoroscopy, changes in pitch related to burr resistance, and excessive vibration due to resistance of burr progression may suggest impending entrapment.

Technical Tips

Management of "stalled" burr Leave the wire in, and follow these steps:

1. Gentle pulling on the burr is rarely successful and can lead to further entrapment.
2. **Rotate.** Disconnect the burr from the advancer (outside the body). Put a hemostat on the rotablator. Rotating the hemostat counterclockwise about 15 times and then gently pulling might affect release.
3. **Balloon angioplasty.** If the burr is still not released, use a second guide and a wire to advance a balloon next to the burr. Inflation at low pressure might release the burr.
4. **Microcatheter.** If the burr is still entrapped, advance a GuideLiner on the "wire/burr unit" all the way to where the burr is stalled in the coronary. This might change the angle and release it.
5. **Surgery.** If all these measures fail, refer for urgent surgery.

For a trapped burr, move the advancer back while advancing the rotawire.

ACTION POINTS

Coronary atherectomy is an invaluable tool to modify complex and heavily calcified coronary plaque. IVUS and OCT can identify the presence and degree of coronary artery calcification. Interventional cardiologists now have a choice in the type of coronary atherectomy device that is used. Operator education and training, appropriate device selection, and experience are imperative to improve clinical outcomes in patients with complex coronary lesions that might otherwise lead to procedural failure. When performing coronary atherectomy, the pericardiocentesis kit and covered stents should be readily available given the risk of coronary perforation.

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CHAPTER 19

Removal of Embolized Material

Mihas Kodenchery, Dat Q. Ha, and Thach N. Nguyen

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CHALLENGES

Percutaneous coronary intervention (PCI) techniques for treatment of coronary artery disease have evolved and diversified dramatically, but they all have at least one common feature: all involve technical manipulation of complex equipment in the confines of coronary arteries and are operated from a significant distance. When traversing severely diseased coronary arteries and manipulating equipment, particularly devices with detachable components, the opportunity for loss or embolization of material in the coronary circulation presents itself. In this chapter, the management strategies for embolized material are reviewed and discussed.

GAME PLAN

When a problem with defective equipment (unexpanded stent, uncoiling wire, asymmetrically bulging balloon due to metal fatigue, twisted guide, etc.) arises inside the coronary artery or the ascending aorta, it is ideal to remove the entire system below the level of the renal arteries so the problem can be corrected without risk of embolization to the brain and any other vital organs.

In the case of a stent that slips off the delivery balloon inside the coronary artery, the stent cannot be simply brought to the iliac artery by withdrawing the whole system, even as a unit. Pulling the indwelling angioplasty wire will leave a loose, free stent behind. All efforts are therefore concentrated on keeping the wire inside the stent and across the lesion for prompt access of rescue devices. If a stent slips off the delivery balloon, there are two options: to retrieve it or to deploy it in a safe, nontarget location.

Once below the level of the renal arteries, the next important step is to remove the embolized stent from the femoral sheath without injury to the femoral artery or the need for arterial cutdown. Everything should be done within an acceptable time frame, with wire still across the lesion. In the meantime, the patient must be closely monitored, and the clinical condition must remain stable so that the scheduled PCI can be continued and finished.

Different options in the management of embolized material are listed in Box 19.1. All techniques discussed in this chapter are used only as references. They range from the standard methods with commercial snares to improvised techniques, which become lifesaving if the procedure is successful. The selection of a particular method or equipment depends on the patient's clinical condition, the operator's familiarity with retrieval equipment, and the availability of the equipment in the cardiac catheterization laboratory. Herein, the discussion focuses more on coronary stents, but the retrieval technique may be applied to any embolized device or fragments.

RETRIEVAL OF AN EMBOLIZED CORONARY STENT

The majority of stents currently in use are of balloon-expandable design. They differ from self-expanding stents, which are generally constructed out of multiple interlacing strands of wire. As coronary stents represent a detachable component of a PCI system, stents are, by their nature, prone to accidental release from the overall apparatus. Significant coronary calcification, tortuosity, and suboptimal guide position can each contribute to stent embolization.

BOX 19.1 OPTIONS IN THE MANAGEMENT OF EMBOLIZED MATERIAL

1. No treatment for peripherally embolized small stents
2. Deploy the embolized stent in an inconsequential location
3. Removal of a tubular stent by a snare
4. Removal of a broken wire segment by a snare
5. Removal of embolized material by a snare made with a loop of angioplasty wire emerged from a transport catheter
6. Removal of tubular stent with two twisted wires
7. Secure a stent by inflating a small balloon distal to it and remove the whole system
8. Remount the stent by a balloon through a transport catheter
9. Grasp a stent with a biopsy forceps at the ostium of a coronary artery

Sometimes, peripheral embolization of stents can be the best option. Systemic embolization does not cause any severe clinical sequelae, except to the cerebral circulation. Short wire fragments retained in a totally occluded artery do not pose any long-term side effects. There are many reports of embolized stents in the lower extremities and periphery without evidence of untoward long-term effects. Any foreign materials that are retained for more than 1 week should not be removed percutaneously because they may be covered and incorporated by fibrous tissue. Aggressive extraction of the embolized material may injure and perforate the vessel.

Risk of Stent Embolization

Coronary risk factors for stripped stents include higher degrees of calcification, tortuous vessels with proximal or moderate-to-severe angulation, previous coronary artery bypass graft surgery, and passage through primary, recently placed, or nonendothelialized stents. Technical risk factors for stripped stents include manually crimped stents, poor support of the guide, increased rigidity of the stent, and direct stenting without complete pre-dilatation [1]. Previously described examples of complications during placement of stents include dislodgement of the stent within the catheter when negative pressure is applied, resulting in detachment from the balloon and allowing the stent to wedge into the distal tip of the guide. Stent migration can happen if a previously placed stent in the proximal portion of the coronary vessel strips the newer stent from its delivery balloon [1].

Clinical Scenarios

Typically, stent embolization occurs in one of three scenarios. First, the stent may be successfully introduced into the coronary circulation, but it cannot be advanced into the target area. This is usually due to proximal tortuosity, a rigid and calcified proximal segment, or insufficient pre-dilatation of the target lesion. Second, in an attempt at direct stenting without pre-dilatation, unexpected difficulty in advancing the stent may be encountered. In these cases, the stent should be gently retracted back into the guide, removed, and the lesion predilated. If the distal tip of the stent has engaged the lesion, it is possible that manipulation to advance the stent may strip the stent off the balloon, such that it remains embedded in the lesion when the balloon is retracted. In this case, the coronary wire is generally still in place, indwelling through the stent lumen and the lesion. Most frequently, stents also become dislodged from the deployment balloon when they are retracted from the coronary artery back into the guide. At that time, the tip of the guide (especially the 90° primary curve of the Judkins right) may catch the proximal edge of the stent and strip it off the deployment balloon. The stent will be left dangling on the coronary wire at or near the ostium of the index vessel under treatment [1].

Tips and Tricks

****How to withdraw a stent without embolizing it?** When a stent is unable to be delivered to the target area because of a tortuous proximal segment or because it is unable to cross a tight lesion, it must be withdrawn into the guide. In this instance, the tip of the guide should be lined up well coaxially with the indwelling wire and its straddling stent. If the guide cannot provide an excellent coaxial relationship with the stent, then the guide should be retracted until a favorable alignment between the guide and stent can be achieved. Sometimes, removal may require retracting the guide to the tip of the femoral sheath to straighten the tip of the guide [2].

REMOVAL OF A STENT WITH A SNARE

Standard Equipment

The Amplatz Goose Neck™ microsnare catheter (Medtronic, Minneapolis, MN, USA) is a nitinol retrieval device that includes a transport end-hole catheter and loop snares. The wire, which moves freely in the catheter, extends from the proximal end of the catheter, out the distal end, and then it is folded and re-enters the distal lumen, extending back to the proximal end. Retraction of one or both ends of the wire causes it to retract into the distal tip. The 4-Fr catheter tapers to a 2.3-Fr tip. The snares are available in 2, 4, and 7 mm diameters. Once emerging from the catheter, the loop is at a right angle with the tip, thus facilitating grasping of the target object. The 4-Fr transport catheter can easily fit inside a 6-Fr guide [3] (Figure 19.1).

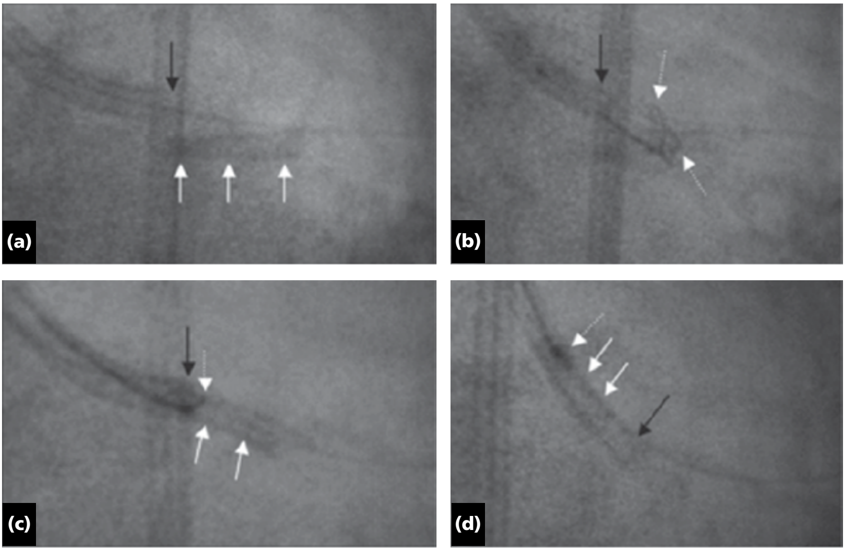

Figure 19.1 Serial angiographic images show the use of a microsnare to entrap and remove an embolized stent from the left main coronary artery. (a) The non-deployed stent (white arrows) is seen inferior to the tip of the guiding catheter (black arrow). (b) The snare (white arrow with interrupted line) is opened and is positioned around the stent (white solid arrows). (c) The snare (white arrow with interrupted line) has been tightened around the stent (white solid arrows) and is being pulled back into the guiding catheter (black arrow). (d) The stent has been fully retrieved into the guide. Source: Reproduced with permission from [4] / John Wiley & Sons.

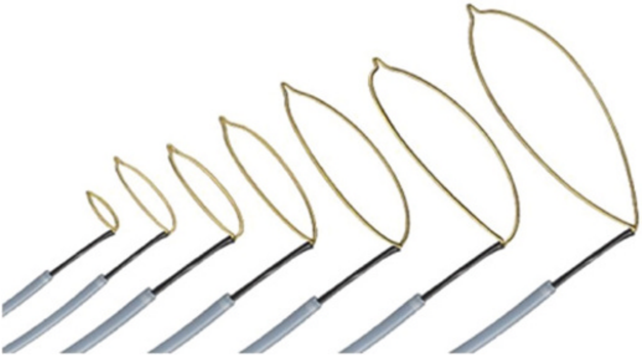

Figure 19.2 Image of Goose Neck Amplatz snare.

Retrieval of a Tubular Stent from the Coronary Artery

Once a stent slips off the delivery balloon, the indwelling wire is advanced as far as possible into the distal vasculature, and the balloon is removed. A 4-Fr transport catheter with a Goose Neck snare is assembled. The loop of the snare, emerging from the transport catheter, is passed over the angioplasty wire, encircles it, and is advanced up to the coronary ostium. Under fluoroscopic guidance, the snare is manipulated into the artery to loop around the unexpanded stent. An effort should be made to grab the distal part of the stent (distal as compared to the position with the heart). Once the loop is in the right position, the transport catheter is advanced to tighten the loop around the stent. Then the guide, with the stent secured by the snare, is withdrawn to the iliac artery as a unit. If extraction of a stent through the usual 6- or 7-Fr femoral sheath is difficult or impossible, the sheath is changed to a larger (9-Fr) one through which the embolized stent can be removed [4]. An embolized broken wire segment or any embolized device can be snatched by the snare with the same technique (Figure 19.2).

Tips and Tricks

****Assembling an improvised snare from angioplasty wire** If there is no commercial snare available, a snare can be improvised by using regular angioplasty wire available in the cardiac catheterization laboratory. The snare is formed by folding a 300-cm long 0.014-in. wire and introducing it through a 4-Fr transport catheter. Once it arrives near the tip of the catheter, one end of the wire is pulled while the other end is advanced slightly to position the sharp point of the tight fold within the catheter so that it will not injure the vessels or cardiac wall during movement of the snare. By advancing one end of the wire while holding the other end until a desired diameter is achieved, a workable loop snare emerges from the tip of the catheter (Figure 19.3). The embolized material is trapped by the snare using the usual technique. After the loop is tightened successfully at the distal end, a hemostat is used to fix the wire in position at the proximal end, and the entire system is pulled as a unit to the iliac artery. [5]

GAME PLAY

The Art of Loop Snaring [6]

The important difference between the commercial and the improvised snare is the angle of the snare at the tip of the transport catheter. The Goose Neck loop is at a right angle with the catheter, while the improvised snare loop is parallel to it. This difference is **vital** in positioning the loop and in assessing

(*Continued*)

its position in the technique of snaring. Once a stent slips off the delivery balloon, the wire should be kept indwelling inside the stent so the free movement of the stent is limited to the longitudinal axis of the wire. That position of the wire would tremendously help the rescue effort by giving prompt access to the defective stent. The Goose Neck Microsnare is inserted into the guide with its loop encircling the angioplasty wire. It arrives at the correct position as its loop is encircling the distal end of the stent (based on its position and the heart). Then, the loop is tightened by advancing the transport catheter, and the whole stent–snare–wire complex is ready to be pulled out. The improvised snare can achieve the same result but requires more skillful manipulation because the loop is not at a right angle to the catheter. In the case of a broken wire segment or a free stent not on an angioplasty wire, their capture depends on correct alignment of the loop to the free end of these free fragments [6].

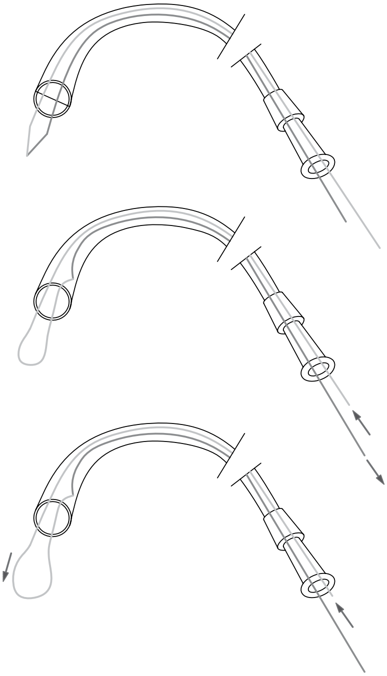

Figure 19.3 Making a snare from angioplasty wire. By advancing one end of the wire while holding the other end until a desired diameter is achieved, a workable loop snare emerges from the tip of the catheter.

Tips and Tricks

****Which end to loop? [6]** The loop snare technique is effective if the embolized fragment (wire or stent) has a free end for ensnarement. The patient is positioned under the fluoroscope to locate both ends of the fragment and identify its free end, which usually pulsates. The operator needs to encircle the free end with the loop [6].

****Critical positioning of the snare perpendicular to the object [6]** The snare is held at right angles to the calculated plane of the embolized fragment. To do this, the patient must be positioned under the fluoroscope in such a way that the wire is seen in its full length. This

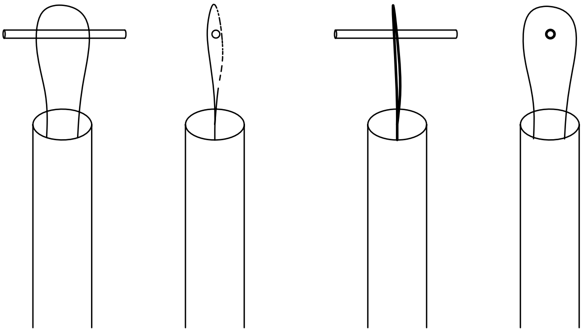

Figure 19.4 The significance of the plane of the snare loop in relation to the broken wire or embolized stent. (a,b) The snare is held in such a way that it is shown under fluoroscopy as a straight line or a closed loop, confirming its vertical plane in relation to the wire or stent fragment.

implies that the wire or stent is vertical to the X-ray beam. Then the snare is held in such a way that it is shown under fluoroscopy as a straight line or a closed loop, confirming its vertical plane in relation to the wire or stent fragment. Next, the free end of the wire can be captured. If the snare loop plane is parallel to the plane of the broken wire or stent, ensnarement is impossible (Figure 19.4).

****Securing the embolized wire fragment [6]** The next important step is to make sure that the snare has encircled the embolized wire or stent. The transport catheter is advanced, causing the broken wire fragment or stent to bend when the snare is engaged. Withdrawing the ends of the wire to capture the embolized wire or stent is not suggested, because it can cause disengagement (the stent or the wire fragment can get out of the encircling loop) (Figure 19.5). Remember to tighten the noose by advancing the transport catheter. Keep the wire immobile.

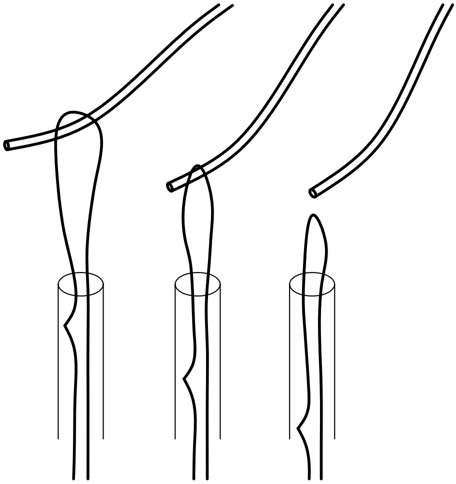

Figure 19.5 Improper technique of ensnarement. Withdrawing the ends of the wire to capture the embolized wire or stent can cause disengagement. (Illustrated by Quoc Nguyen).

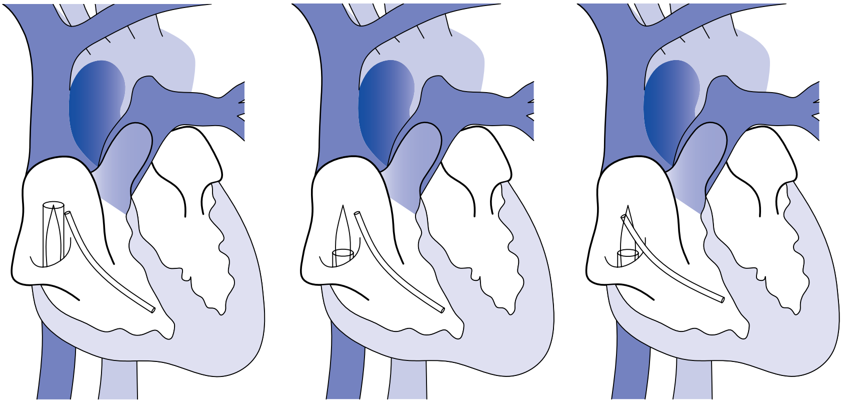

Figure 19.6 Technique of ensnarement with a pointed loop. When the tip of the catheter arrives near the embolized object, it is positioned with its tip cephalad to the object, and the wire loop, still well inside the catheter, is at the upper level of the object. While the wire loop remains in place, the catheter is withdrawn to expose the loop. (Illustrated by Quoc Nguyen).

****How to manipulate a pointed loop safely** If the stiff, folded end of the loop cannot be withdrawn into the catheter to make a round loop outside the tip of the catheter, the pointed loop is kept inside the transport catheter during transit. When the tip of the catheter arrives near the embolized object, it is positioned with its tip cephalad to the object, and the wire loop, still well inside the catheter, is at the upper level of the object. While the wire loop remains in place, the catheter is withdrawn to expose the loop. This technique is helpful in preventing vascular injury from the stiff, folded end of the pointed loop [6] (Figure 19.6).

EXOTIC TECHNIQUE

***The "Hairpin-trap" Technique

This is a method in which a hydrophilic, polymer-jacketed wire is bent ~5 cm from its distal tip (Figure 19.7a–c). The hairpin tip is inserted into the Tuohy valve (Figure 19.7d) and exits through the distal tip of the guide (Figure 19.7e). The hairpin is advanced in the target vessel and then withdrawn, "hooking" the lost stent (Figure 19.7f). The wire tip is pulled back into the guide (Figure 19.7g), and a balloon is subsequently inflated inside the guide (Figure 19.7h,i), "trapping" the wire and securing the hairpin, hence preventing inadvertent release of the stent [7].

REMOVAL OF A STENT WITH A BALLOON

The technique is to advance a small 1.5- or 2.0-mm balloon over the wire and through the stent and inflate the balloon distal to the stent. Retracting the balloon will then bring the stent back into the guide. If the balloon cannot be advanced all the way through the stent, low-pressure inflation of the balloon when it is at least partially within the stent will suffice. In many cases, the system may be removed without loss of the coronary wire position or removal of the guide. This will be easiest if a 7- or 8-Fr guide is used. In some cases, the stent may be contained within the distal tip of the guide, but the inflated balloon cannot be retracted into the guide. In this

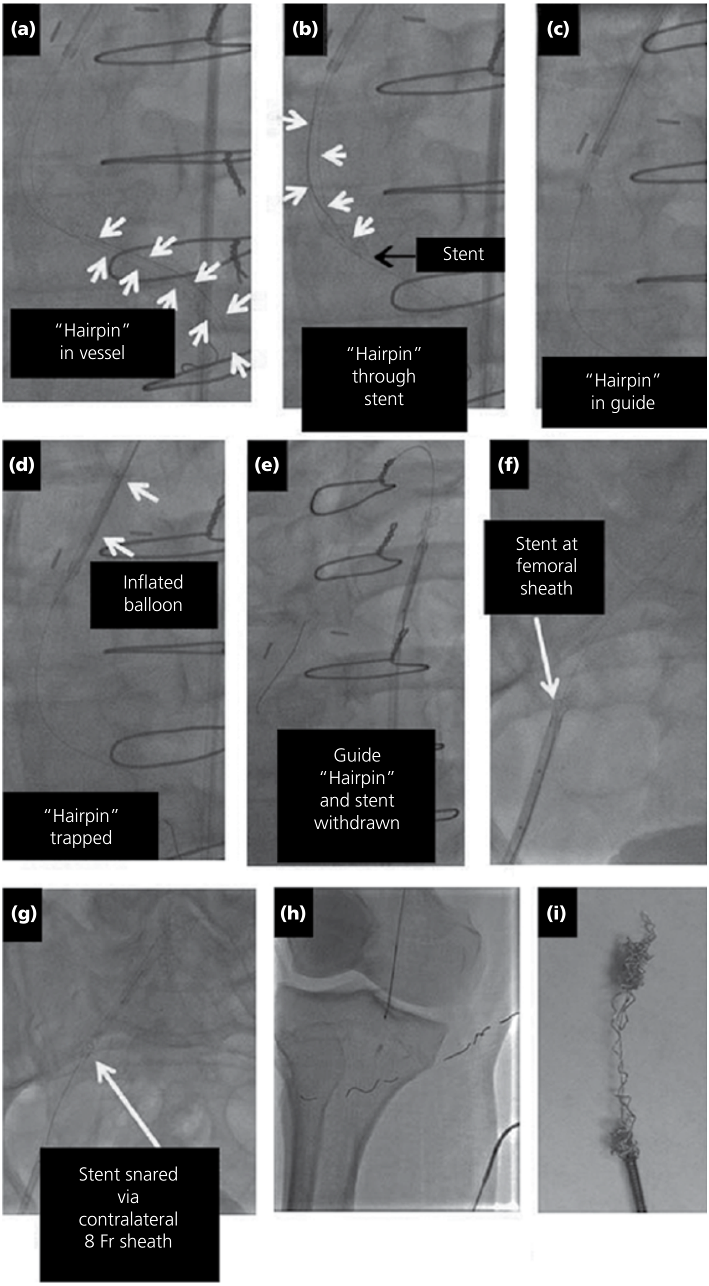
(a)
"Hairpin" in vessel
(b)
Stent
"Hairpin" through stent
(c)
"Hairpin" in guide
(d)
Inflated balloon
"Hairpin" trapped
(e)
Guide "Hairpin" and stent withdrawn
(f)
Stent at femoral sheath
(g)
Stent snared via contralateral 8 Fr sheath
(h)
(i)

Figure 19.7 The "hairpin" formed by the wire is advanced into the saphenous vein graft to the right posterior descending artery (a) and withdrawn, "hooking" the lost stent (b). The wire tip is reinserted into the guiding catheter (c), where it is "trapped" by inflation of a balloon (d), and the entire "hairpin-trap-stent assembly" is withdrawn from the saphenous vein graft (e). The assembly could not be inserted in the ipsilateral femoral artery sheath (f) but was successfully snared via an 8-Fr contralateral femoral artery sheath (g). After inadvertent wire removal, the lost stent embolized to the right tibioperoneal trunk, from where it was successfully snared (h,i).

case, the guide and balloon should be removed as one unit over the wire. An extension wire will allow preservation of coronary access. The removal of an inflated balloon from a coronary artery is not without danger. The balloon should have a very low profile, and the artery should be large enough to easily accommodate the movement of an inflated balloon.

REMOVAL OF A STENT WITH TWO WIRES

When a snare is not available to remove the embolized stent, it may be possible to withdraw the free stent with a second wire twisting around the stent to immobilize it relative to the first wire [8].

Tips and Tricks

****Manipulation of wires to remove an embolized stent** Once a stent slips off the delivery balloon, the wire should be kept indwelling inside the stent so that the free movement of the stent is limited to the longitudinal axis of the wire. To remove this free-standing stent with wires, a second wire should be advanced and pass through the struts of the unexpanded stent and not through the central lumen. If the stent is partially-expanded, the size of the cell is large enough to accommodate the tip of a second wire. Once the second wire has been advanced as far as possible, the two wires are twisted proximally with the stent straddling their stiff segment. The stent is trapped between the two entangled wires and removed. To be successful in entrapping the stent, both wires should be advanced deeply so the stent is straddling their stiff part. A soft, floppy distal tip is not strong enough to entrap a stent when twisted. As the wires are removed slowly, the guide engages deeper into the ostium. This is the sign that the stent has been properly snared. Theoretically, if the second wire goes through the central lumen of the stent, both wires can be easily pulled out, leaving the free stent behind, so the second wire should strategically go through the side struts and not the central lumen. With gentle and persistent pulling, the whole system (guide, stent trapped between two entwisted wires) will be successfully withdrawn [8].

DEPLOYMENT OF AN EMBOLIZED STENT

Proper management of this situation is generally straightforward. The deployment balloon should be advanced back over the wire and fully into the stent. Even if the stent is not advanced completely through the lesion, it should be expanded in its current position to its fullest possible dimension using the deployment balloon. If the deployment balloon cannot be advanced through the stent, a lower-profile, flexible-tipped balloon catheter should be inserted instead. Use of a very small diameter (1.5–2.0 mm) balloon will facilitate entry of a subsequent larger balloon if a nominally sized balloon will not pass through. It is virtually always possible to advance a balloon at least partway through the stent and open it partly. The remainder of the stent can be expanded sequentially. Occasionally, a new, smaller balloon will be needed to pass through the unopened portion of the lost stent. Predilatation of the target lesion (usually possible with the balloon used to expand the initial stent) will ensure success with additional stent implantation efforts.

SHARP THINKING

To Deploy or to Remove an Embolized Stent?

It is important to decide whether to deploy or to remove an embolized stent right at the start, because once a stent is partially deployed, it will have to be perfectly deployed with its struts well apposed to the arterial wall (as in any standard stenting procedure). A half-deployed stent that obstructs the flow will cause early or late acute vessel occlusion. So, either the stent must be perfectly deployed, or it must be removed. It is easier to remove an intact (not-yet-deployed) stent than to remove one later with its struts sticking out or after being crushed or disfigured. It is also easier to deploy a stent at the time when the patient is still stable rather than re-cross later an artery acutely occluded by thrombus obstructing a partially deployed stent in the setting of acute myocardial infarction.

If the operator attempts to open the proximal half of a stent, they should try to open it as wide as possible because another balloon will have to be re-inserted at the imperfect opening that has just been created. If the opening of the stent is small or crooked, the second attempt to re-insert a larger balloon could be difficult. Once the stent is deployed, it will be re-crossed by other interventional devices (including a new stent) to dilate and stent the distal index lesion. If the first (embolized) stent is not well deployed and the lumen is not large enough, PCI of the distal index lesion could be very hard and almost impossible. Contemplating all these challenges beforehand will help the operator to make a wise decision, whether to remove an embolized stent with a snare or to deploy it perfectly.

REMOVAL OF FRACTURED WIRES

Virtually every coronary angioplasty device is advanced into the coronary system over a wire. The soft, atraumatic tips of coronary wires have been known to fracture off secondary to excessive manipulation and then to embolize in the coronary circulation. This most frequently occurs when the shapeable wire tip becomes lodged in an atherosclerotic plaque and separates from the body of the wire when the wire is retracted. This occurred somewhat more frequently in the past, when nearly all wires were manufactured by bonding a flat ribbon to the round end of a wire. Current coronary wires are constructed of a gradually tapering filament that is an extension of the shaft of the wire. As a result, solder points and other relatively weak junctions are minimized in contemporary wire design. Nonetheless, fracture of wire tips may still occur.

The distal end of the ViperWire was fractured during orbital atherectomy. The fractured wire fragment was left in the sub totally occluded obtuse marginal vessel with no adverse outcome.

Withdrawal of an Uncoiling Ribbon of Wire

After excessive manipulation of a wire (more than a 180° turn), its distal segment can become uncoiled. This is detected as a radiolucent segment at the distal tip. Instead of pulling the wire to remove it from the coronary system, the best technique involves proper seating of the guide, then advancing an over-the-wire balloon or a transport catheter over the whole wire, including the uncoiled segment, if it tracks easily. After the radiolucent segment has been advanced over by the balloon or a transport catheter, the whole system – guide, catheter, and wire – is removed as a unit. If the balloon catheter does not track easily over the floppy tip, it may dissect the artery. In this case, it may be better to simply pull the wire and all the devices as a unit. If the distal tip of a wire has been broken, this segment of the wire could be removed by tangling the broken tip with two more non-polymer wires advanced distally from the unbroken segment.

Tips and Tricks

****Removal of wire fragment** Recovery of wire fragments is generally accomplished relatively simply through insertion of two or more additional angioplasty wires into the coronary artery under treatment. The proximal ends of the wires are inserted together in a torque device, which is firmly screwed and rotated many times in a circular pattern. During this rotational motion, the broken segment is entangled within these rescue wires, and all three wires are then removed together. When this technique fails, a retrieval device such as a snare is needed for removal of these wire fragments.

REMOVAL OF EMBOLIZED MATERIAL FROM THE ILIAC ARTERY

Once the embolized object has been brought to the iliac artery, the main problem is to remove it through the vascular sheath without the need for arterial cutdown. If the 6- or 7-Fr sheath is too small, the sheath should be changed for a 9-Fr sheath. Biliary forceps, alligator forceps, or a cardiac bioptome are suitable for retrieving the stent in the common iliac artery or at the tip of the arterial sheath. Coil stents have been successfully retrieved by using the alligator forceps [9], and tubular stents have been successfully retrieved by using the bioptome [10]. The disadvantages of these instruments are

1. the need to directly grasp the relatively small stent
2. the likelihood of damaging the stent itself
3. the possibility of endovascular trauma
4. the loss of wire position during stent retrieval.

Hence, innovative techniques have been developed for stent retrieval using easily available instruments. Most of the stents available today are radio-opaque and not difficult to locate under fluoroscopy. These removal devices are mainly used when the embolized material is brought to below renal artery level (Figure 19.8). Familiarity with each removal device can be extremely useful in the rare event of stent misplacement.

BASKET RETRIEVAL DEVICE

The basket retrieval device is designed for capturing biliary stones and other irregularly shaped elements within tubular biological structures. The device consists of helically arranged loops that can be collapsed or expanded by retracting or advancing a lever on the proximal end of the system. When a stent is dangling from a coronary wire, advancement of a basket retrieval device over the wire will bring it into proximity to the stent. Retraction of the basket traps the stent, and the entire system can be retrieved safely.

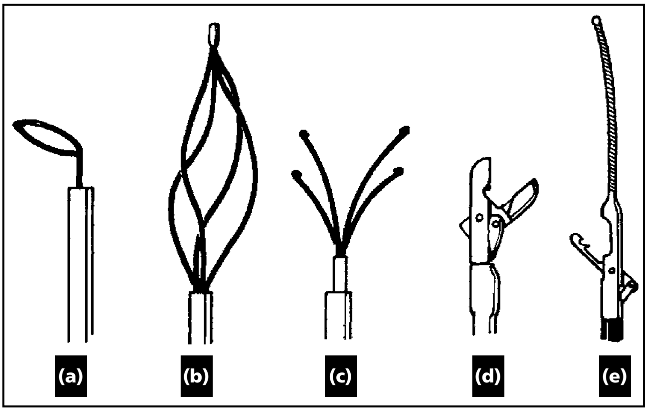

Figure 19.8 Different devices for the removal of foreign bodies.

Tips and Tricks

****Best use for a basket retrieval device** The device can be used to catch a stent from one side and pull it free from a deployment balloon. It works best if the stent has been damaged and misshapen such that a portion of it projects laterally away from the deployment balloon [2].

BIOPSY OR ALLIGATOR FORCEPS

Alligator forceps are familiar to most cardiologists. The design of standard myocardial bioptomes follows the design principles of alligator forceps. This type of forceps device is used widely throughout medicine and surgery. The “biting jaws” action of these devices makes them attractive for capturing embolized material. A variety of these devices are available in most hospital settings, but most are not suitable for use within the vascular tree because the catheter bodies have insufficient length, the shaft diameter is too large, or the devices are too rigid to be advanced safely into the coronary arterial system. Thinner, softer, disposable bioptomes are generally immediately available in catheterization laboratories and can be used, but they are still generally too rigid for use beyond the ostium of a vessel. Bioptome jaws are quite sharp, so gripping any device must be attempted with great care to avoid severing thin metallic structures [2].

Tips and Tricks

****Retraction of a stent into a guide** Once the stent has been brought to the iliac artery, it is manipulated to be withdrawn into a guide if there is a favorable alignment between the stent and the guide. In these situations, the guide may be retracted into the arterial sheath to straighten its tip. If there is no excellent coaxial relationship, the stent could be stripped off the balloon [2].

****Stent removal from the iliac artery with a commercial snare** Position the snare above the stent and tighten it at the distal end of the stent (as the heart is the point of origin) under fluoroscopic control. The stent can now be pulled into the guide and retrieved. The stent should be snared at the distal end, which is close to the operator. By pulling this end, the operator can manipulate the end to enter the tip of the femoral sheath and be removed from the body. If the stent is snared at the proximal end, it is more difficult to manipulate the stent to enter the guide or the femoral sheath. If the stent is crushed from the proximal end, the whole stent will collapse, and its large mass is difficult to pass through the femoral sheath. If the stent is crushed at the distal end, there is only a small area of damage, and it can still be manipulated to get it into the sheath. Changing to a larger size (9-Fr) sheath will help to get the stent to enter the sheath [2].

****How to upsize a larger sheath over two angioplasty wires and catheters** Consider a case in which the stent has slipped off the balloon [11]. In this case, advancing the snare and capturing the stent was a straightforward procedure, but the combined stent and snare proved too bulky for retrieval through the 6-Fr sheath. The greatest challenge was to exchange the 6-Fr sheath for a larger 8-Fr model over the snare and coronary wire. The 4-Fr snare catheter was removed, and it was attempted to keep the snare noose in place. The coronary wire had to remain advanced through the stent if the stent came loose from the snare. The inner lumen diameter of the 8-Fr sheath dilator could not accommodate both the snare shaft and the coronary wire. A 6-Fr dilator was advanced over the snare shaft within the 8-Fr femoral sheath, while the smaller dilator within the larger sheath allowed the coronary wire to remain between the sheath and dilator. After this successful maneuver, the snared stent was retrieved outside the patient’s vasculature through the 8-Fr sheath with no damage to the vessel wall [11].

ACTION POINTS

Embolization of equipment into the coronary tree is dominated by the loss of stents in today's interventional practice. Loss of stents typically occurs because of inadequate pre-dilatation of the target lesion and/or improper guide alignment with the coronary ostium. Extreme tortuosity and extensive plaque calcification also contribute to the odds of coronary stent loss. The most important consideration in avoiding complications associated with stent embolization is to select appropriate tools and strategies for managing the planned intervention. Use of routine pre-dilatation of a target lesion, careful guide alignment with the ostium of the target vessel, and appropriately supportive wires will minimize opportunities for stent loss. Specific retrieval techniques to recover lost stents are described. The most consistent, easiest to use, and readily available devices are the coronary loop snares, but all the devices described may have an important role to play in the event of embolized coronary equipment. Familiarity with, and immediate access to, these devices is important in contemporary practice.

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CHAPTER 20

Intravascular Lithotripsy

Rajesh Sachdeva, Nihar Jena, and Gautam Kumar

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CHALLENGES

Coronary artery calcification presents a significant challenge to stent delivery, expansion, and apposition – key factors influencing early stent thrombosis and late restenosis during vascular healing. Calcium modification before deployment of a stent is a critical procedural step, and as the population ages, managing heavily calcified lesions has become increasingly difficult, posing a substantial barrier to achieving optimal interventional outcomes [1]. Calcium modification can be done using various methods; one of the novel and safer approaches is Shockwave® intravascular lithotripsy (IVL) (Shockwave Medical, Inc. Santa Clara, CA). In the Disrupt CAD III study [2], IVL treatment led to multiplane and longitudinal calcium fractures that facilitated safe and effective stent implantation. Furthermore, based on sub-analysis by IVUS [3], the use of IVL is associated with improved vessel compliance, facilitating optimal stent implantation in de novo severely calcified lesions.

(*Continued*)

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*Basic; **Advanced; ***Rare, exotic, or investigational

$, <100.00 $US extra; $$, >100.00 $US extra

⌛, <10 min extra; ⌛⌛, >10 min extra

💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
Edited by Thach N. Nguyen, Thuong Dzung Ho, Khiem D. Ngo, Mihas Kodenchery, Gianluca Rigatelli, Marco Zuin, Shao Liang Chen, and C. Michael Gibson.
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The IVL balloon catheter is a rapid exchange system that can be delivered over a 0.014-inch guidewire. Despite the presence of ultrasonic emitters, the minimum diameter of the balloon profile is 2.5 mm. The crossing profile ranges from 0.044 to 0.047 inch [4]. The balloon size is reasonable to deliver in most of the calcified lesions. However, severely calcified lesions, distal lesions, and tortuous vessels might impose a challenge in positioning the balloon appropriately and may require lesion modification with atherectomy prior to IVL.

The IVL system works on eccentric and concentric, superficial, and deep calcification by creating microcavitation bubbles and transmitting ultrasonic energy to the luminal and deep-seated calcium. This results in calcium fractures, sparing damage to the soft tissue [5].

The presence of nodular calcium can sometimes result in balloon rupture, which will require another IVL versus other modalities like atherectomy. Combining different atherectomy methods with or without simple balloon angioplasty may be needed for optimal lesion preparation [6].

The IVL balloon is inflated to 4–6 atm and a pulse per second and up to 10 pulses are delivered in one cycle, which can be detrimental in high-risk and hemodynamically compromised patients. This can be avoided by carefully choosing the lesion and planning with mechanical circulatory support in selected high-risk cases, especially left main and ostial left anterior descending artery lesions.

BEST PLAYERS

Standard of Excellence

IVL is based on the already established technology of extracorporeal shockwave lithotripsy of kidney stones. The expectation is to form a fracture in the calcium in the plaque without disrupting the vessel. The Coronary Shockwave® balloon can deliver 10 pulses in each cycle, up to 80–120 pulses (C2/C2+ catheter, respectively).

The ideal outcome is microfractures in superficial and deep calcium. Sometimes, the effect can be visualized while delivering the therapy in focal constricted lesions by the expansion of the balloon. The lesion should be accessed by orthogonal angiographic view along with intravascular ultrasound (IVUS) or optical coherence tomography (OCT) for a better visualization of lesion preparation before delivering stents.

BEST PLAYERS

Description of the Device

The Shockwave® IVL device has three components: IVL generator, IVL connector cable, and IVL catheter (Figure 20.1).

An IVL generator is a battery-powered portable device that acts as a power source to provide electricity to the IVL emitters. It has a charging port and a catheter connecting port. There is a power button to turn the device on or off. The IVL emitters can be activated from the generator by another push button. A display shows the battery status and the number of IVL therapies available [4].

The IVL connector cable, as the name describes, connects the generator to the IVL catheter. The connector has a push button to activate IVL therapy [4].

The IVL catheter is available at 0.014 inch over the wire or rapid exchange system. It consists of ultrasound emitters surrounded by a balloon. The balloon is of constant length and has different diameters ranging from 2.5 to 4.0 mm. The catheter has a working length of 135 cm and is compatible with a 6-F guide. The catheter has two versions based on the number of pulses it can deliver. The Shockwave C^2 catheter was initially introduced with 80 pulses, and the newer Shockwave C^{2+} catheter can deliver up to 120 pulses [4].

The balloon size is chosen based on the vessel size. Usually, a 1:1 balloon-to-vessel ratio is recommended. As with any other procedure, the deliverability and completion of lithotripsy are highly operator-dependent.

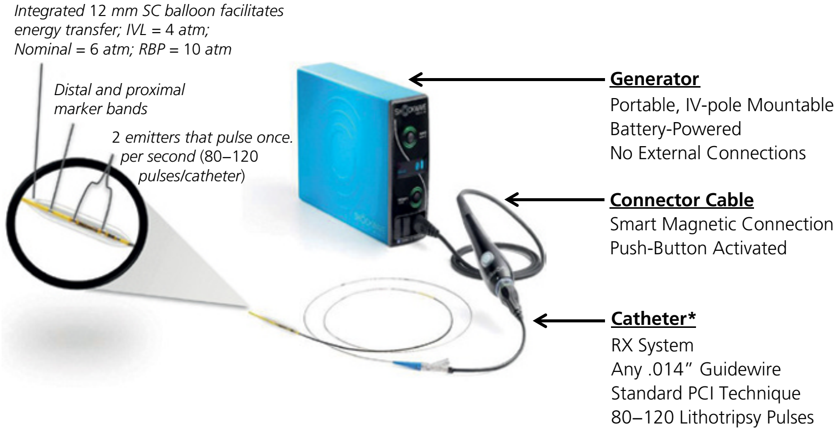
Integrated 12 mm SC balloon facilitates energy transfer; IVL = 4 atm; Nominal = 6 atm; RBP = 10 atm
Distal and proximal marker bands
2 emitters that pulse once. per second (80–120 pulses/catheter)
Generator
Portable, IV-pole Mountable
Battery-Powered
No External Connections
Connector Cable
Smart Magnetic Connection
Push-Button Activated
Catheter*
RX System
Any .014” Guidewire
Standard PCI Technique
80–120 Lithotripsy Pulses

Figure 20.1 Shockwave® intravascular lithotripsy: IVL generator, IVL connector with therapy button, IVL catheter connector, IVL balloon in deflated state. Source: Shockwave.

Discriminating Differences

Shockwave® Medical is the sole manufacturer of IVL devices at present. However, it is worth mentioning that different atherectomy devices are available for calcium modification and lesion preparation before stent delivery. The athero-ablative and other balloon-based calcium modification techniques have higher complication rates, including perforation, no-reflow, flow-limiting dissection, and myocardial infarction, compared to IVL [7].

1. **Cutting balloon, scoring balloon, and nonslip element balloon** These types of calcium modification balloons are based on the concept of focused force angioplasty. The cutting balloon has three to four metallic blades that cut through the calcification. The scoring balloon has helical or linear nitinol wires, providing additional tensile strength and minimal slippage to avoid healthy tissue damage. The nonslip element balloon has three nylon elements that act similar to the scoring balloon [8].
2. **Rotational atherectomy** As the name describes, the device consists of a rotating olive-shaped burr coated with diamonds. The burr ranges from 1.25 to 2.50 mm in diameter with a rotational speed ranging from 150 000 to 250 000 rpm. The rotational atherectomy removes calcified plaques in a differential cutting manner, sparing the soft plaque. The micro-calcified particles generated from the atherectomy are removed by coronary microcirculation. The device can be operated over a specialized 0.009-inch wire [9].
3. **Orbital atherectomy** This device consists of a 1.25-mm diamond-coated eccentrically mounted crown utilizing a 0.012-inch wire. It has two speeds for therapy: low 80 000 rpm and high 120 000 rpm. Orbital atherectomy implements centrifugal forces as it advances through the coronary artery. The distinguishing feature of orbital atherectomy is that it is bidirectional, so there is less chance of device entrapment [10].

GAME PLAN

Advancement, Positioning, and Inflation of the IVL

The IVL balloon is initially prepared by replacing the air with a 1:1 mixture of saline and contrast. It is then advanced over a 0.014-inch guidewire. After loading the balloon onto the wire, the operator or assistant must maintain gentle traction on the wire to create a stable rail, facilitating controlled advancement of the IVL catheter. Advancing the balloon slowly and with

(*Continued*)

steady pressure is crucial to prevent catheter kinking. Once the catheter exits the guiding catheter, its position should be confirmed under fluoroscopy. The IVL catheter contains two radiopaque markers to assist with precise placement [4].

Balloon positioning can be verified by referencing a prior angiogram, acquiring a new angiographic image, or visualizing calcifications under fluoroscopy. Upon confirming accurate placement, the balloon is inflated to 4 atm, and IVL therapy is initiated by activating the push button. Following therapy delivery, the balloon is further inflated to 6 atm before deflation [4].

CONFRONTING THE CHALLENGES

Failure to Cross a Lesion

The current generation of IVL balloon catheters features a bulkier profile (crossing diameter of 0.044–0.047 inch) compared to conventional balloons, making lesion crossing particularly difficult in cases of severe stenosis. Forceful advancement of the device under such conditions can displace the guiding catheter or cause guidewire prolapse into the aorta. However, this challenge can be addressed through various strategies depending on vessel anatomy, lesion location, and calcification severity.

Successful delivery of the IVL catheter hinges on selecting appropriate techniques and equipment. The choice of a guiding catheter that provides sufficient support is crucial. In cases where the IVL balloon cannot be advanced, deep engagement of the guide catheter may improve coaxial alignment and facilitate crossing. Additional techniques include the use of a guide extension catheter, a stiffer guidewire, or a buddy wire. In tortuous anatomies – particularly the right coronary artery – having the patient take a deep breath and hold it may temporarily straighten the vessel and allow advancement.

Predilatation with a smaller-profile balloon may create sufficient space to permit delivery of the IVL catheter. In heavily calcified or uncrossable lesions, upfront lesion modification using rotational or orbital atherectomy followed by IVL has shown efficacy.

Tactical Approaches to IVL Delivery in Severely Stenotic Lesions

1. **Optimize Guide Suppor**t. Ensure stable guide catheter positioning. Switch to a more supportive catheter or engage it more deeply for coaxial alignment and enhanced pushability.
2. **Use Patient-Assisted Maneuvers**. In tortuous segments, particularly the right coronary artery (RCA), instructing the patient to take and hold a deep breath can aid catheter advancement.
3. **Select a Stiffer Wire**. A stiffer guidewire enhances catheter tracking and stability.
4. **Utilize Guide Extension Catheters**. They can facilitate balloon delivery to distal or resistant lesions and improve support.
5. **Consider a Buddy Wire**. An additional wire can assist with device delivery and may be left in place during lithotripsy to stabilize the system.
6. **Perform Balloon Predilatation**. Pre-inflation with a smaller-diameter balloon can create a lumen sufficient to advance the IVL balloon.
7. **Adjunctive Atherectomy**. In highly calcified or uncrossable lesions, rotational or orbital atherectomy may be required prior to IVL deployment.

Tips and Tricks

1. **Lesion Selection.** An initial angiographic assessment should identify suitable calcified lesions. Lesion characteristics help determine whether IVL should be a first-line therapy or an adjunct.

2. **Imaging Guidance.** Intravascular imaging using IVUS or OCT should be performed when feasible. OCT offers higher resolution for calcium characterization but may be limited by contrast load, device availability, and crossing limitations in tight stenoses, due to its softer catheter shaft and short monorail system. A calcium arc >180°, deep, and long segment calcification are optimal indication for IVL.
3. **IVUS-based Strategy.** In our practice, IVUS is used to assess lesion crossability. If the IVUS catheter traverses the lesion, IVL catheter delivery is generally feasible. If it fails to cross, there is a need to proceed with lesion modification via atherectomy or balloon angioplasty before attempting IVL.
   a. Inability to cross with an imaging catheter should prompt atherectomy as an adjunctive initial approach and if unavailable, consider balloon angioplasty with smaller size balloon.
   b. Atherectomy is preferred as an initial approach if calcific nodule is identified.
   c. Presence of deep calcium and/or ISR in an under-expanded stent should prompt ultimate use of IVL in an effort to obtain circular and compete stent expansion.
4. **Visualize the Balloon Under Fluoroscopy While Delivering the Therapy.** The IVL balloon is inflated to 4 atm, and the treatment is delivered; however, it is essential to visualize the expansion of the narrowed calcified portion, which usually expands as the calcium breaks. This might not always happen depending on the severity of the lesion but if noted, it is a good marker for optimal calcium modification.
5. **Use of Other Modalities as an Adjunct Before or After IVL.** Using traditional angioplasty to create enough passage to deliver the IVL balloon and sometimes using atherectomy might be helpful in severe lesions. Post-therapy imaging can reveal calcium fractures and adequate lesion preparation for stent delivery. Adding a noncompliant balloon to expand the lesion segment further can be beneficial for adequacy of lesion preparation prior to stenting. Critically stenotic lesions, heavily calcified lesions, and extreme tortuosity are challenges to delivery of the lithotripsy balloon to the target lesion. Judicious use of supportive guides, predilation with balloon, atherectomy, and guide liner often facilitate the delivery of intravascular lithotripsy balloon to the target lesion.
6. **Ensure 2-mm Overlap Between the Treatment Segments.** While treating longer lesions, it is imperative to have at least 20 pulses in one region and 2-mm overlap in subsequent IVLs. More than one balloon can be utilized if needed based on lesion severity and pulse requirement.
7. **Observe the Hemodynamics and ECG.** During the delivery of IVL therapy, it is crucial to allow adequate recovery time between therapy sessions. The patient might become hypotensive and bradycardic, or the ST segments might change due to transient ischemia. Allowing time between and stabilizing the hemodynamics will improve the overall outcome. The operator should not have a false feeling of security with low-pressure balloon inflation during IVL. Even though the balloon is inflated at 4–6 atmospheres, the calcified lesions are exposed to 50 atmospheres. There is an inherent risk of dissection and perforation. The operator should be cautious and prepared to handle them if it happens.

Real-time Actions

Primary elective with strong indication and no problem with device crossing A 74-year-old man with diabetes mellitus type 2, hypertension, hyperlipidemia, sleep apnea, chronic obstructive pulmonary disease (COPD), glaucoma, and status post dual chamber pacemaker for symptomatic bradycardia with negative nuclear scan underwent coronary angiography for Canadian Cardiovascular Society class II on optimal antianginal therapy. Coronary angiography showed calcific intermediate stenosis (Figure 20.2a and Video 20.1) with resting full-cycle ratio (RFR) of 0.86 and fractional flow reserve (FFR) of 0.77. IVUS showed 360° superficial calcium (Figure 20.2b and Video 20.2). Primary IVL treatment with 3.5 × 12 mm Shockwave® balloon was performed (Figure 20.2c and d and Videos 20.3 and 20.4). Balloon ruptured after 2 cycles with 20 impulses. Repeat IVUS (Figure 20.2e and Video 20.5) showed

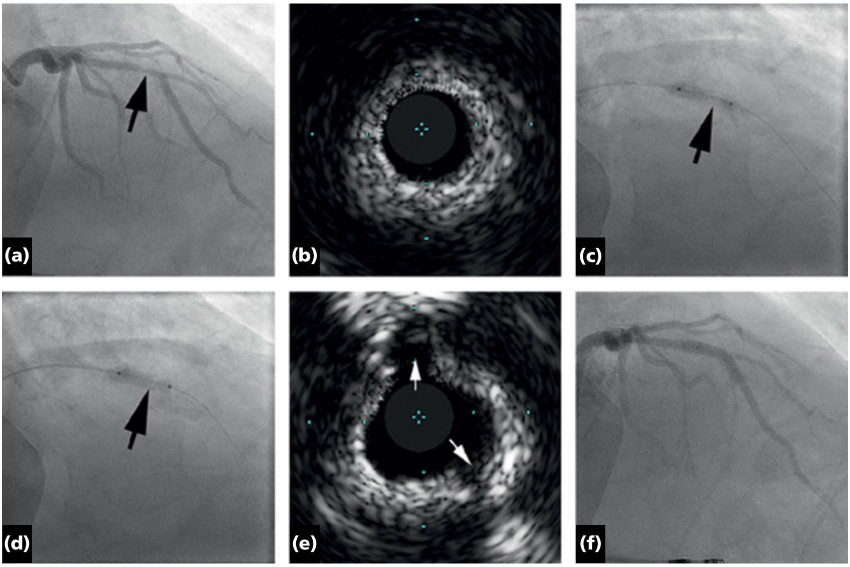

Figure 20.2 (a) Left anterior oblique (LAO) cranial view. Black arrow showing stenotic lesion in mid left anterior descending artery (LAD). (b) IVUS of the stenotic LAD showing 360-degree superficial calcification. (c) 3.5 × 12 mm IVL balloon inflated to 4 atmospheres with black arrow showing dog boning deformity. (d) IVL balloon after treatment with black arrowing pointing to inflation of balloon at the previous image deformity. (e) IVUS image of the calcified stenosis in image (b) now with two big fractures in the plaque (white arrows). (f) LAO cranial projection of the mid LAD post stenting of the stenotic lesion.

fractures in calcium with subsequent balloon angioplasty and stent placement (Figure 20.2f and Video 20.6), followed by post-dilatation with noncompliant OPN balloon (SiS Medical, Frauenfeld, Switzerland).

Video 20.1 Coronary angiography showed calcific intermediate stenosis

Video 20.2 IVUS showed 360° superficial calcium

Video 20.3 & 20.4 Primary IVL treatment with 3.5 × 12 mm Shockwave® balloon was performed

Video 20.5 Repeat IVUS showed fractures in calcium with subsequent balloon angioplasty

Video 20.6 Final angiogram post stent

Secondary elective due to inability of device crossing An 82-year-old male with a medical history of heart failure (left ventricular ejection fraction 30%), coronary artery disease, status post five-vessel coronary artery bypass surgery, aortic stenosis, hypertension, hyperlipidemia, COPD, and chronic kidney disease presented with acute decompensated heart failure and non-ST elevation myocardial infarction (NSTEMI). A year before this presentation, he had a failed attempt to cross the left circumflex (LCX) stenosis with a balloon. Coronary angiography showed previous high-grade stenosis in proximal LCX artery (Figure 20.3a and Video 20.7). The graft to obtuse marginal was known to be occluded. After crossing the stenosis, rotational atherectomy was performed with 1.5 mm burr at 170 000 rpm. The proximal LCX was treated

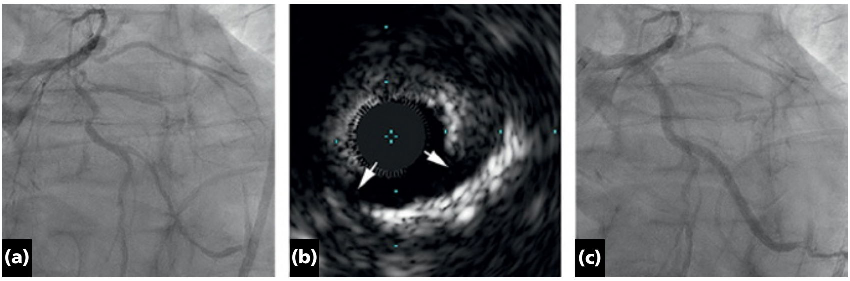

Figure 20.3 (a) LAO caudal projection showing high grade stenosis in proximal LCx and obtuse marginal. (b) IVUS post rotational atherectomy and IVL treatment showed fractures (while arrows). (c) LAO caudal projection showing final results post stenting.

with an IVL 3.0 × 12 mm balloon that ruptured after delivering 20 pulses at nominal pressures. Then using an IVL of 3.5 × 12 mm with 70 pulses at 6 atm were delivered to the proximal LCX. IVUS showed fractured calcium (Figure 20.3b and Video 20.8). The stents were successful with TIMI 3 flow (Figure 20.3c and Video 20.9).

Video 20.7 Coronary angiography showed previous high-grade stenosis in proximal LCX artery

Video 20.8 IVUS showed fractured calcium

Video 20.9 Final angiogram after stenting.

Secondary rescue due to undilatable stenosis A 52-year-old male with a history of prior cerebrovascular accident, coronary artery disease (status post three stents), diabetes mellitus type 2, hypertension, and hyperlipidemia presented with unstable angina and shortness of breath with exertion. Coronary angiography showed hemodynamically significant focal in-stent restenosis (ISR) of the distal RCA (arrow) with FFR of 0.69 (Figure 20.4a and Video 20.10). Percutaneous coronary intervention was performed with Chocolate balloon catheter (Medtronic, Minneapolis, MN), followed by placement of Xience Alpine drug eluting stent (Abbott, Lake County, IL). However, there was residual napkin ring stenosis that did not yield with further post-dilatation with 3.25-mm NC Trek balloon catheter (Abbott, Lake County, IL) at 30 atm pressure (Figure 20.4b and Video 20.11**)**. IVUS confirmed under-expansion of the stent with calcification behind the initial stent and more proximal calcific nodule. Off-label Shockwave® lithotripsy balloon catheter 4.0 × 60 mm was used 3 weeks later. Two cycles of 30 impulses were delivered at 4 atm, and balloon was deflated. In an attempt to reinflate the balloon, there appeared to be contrast tracking toward the proximal RCA beyond the balloon margins under the previous stents (Figure 20.4c and Video 20.12) with migration to the coronary cusp. IVUS was performed that revealed an intramural hematoma behind the stented segment in the mid- and proximal segment of the RCA (Figure 20.4d and Video 20.13). Further IVL was performed with a new balloon (Figure 20.4e and Video 20.14); optimal stent expansion was achieved in distal RCA ISR, proximal segment that was without a stent was stented, and ostium was flashed with ostial flash balloon (Figure 20.4f and Video 20.15).

Video 20.10 Coronary angiography shows focal in-stent restenosis (ISR) of the distal RCA.

Video 20.11 Residual napkin ring stenosis that did not yield with post-dilatation with 3.25-mm NC Trek balloon catheter at 30 atm.

Video 20.12 Angiogram after Off-label Shockwave® lithotripsy balloon catheter 4.0 × 60 mm, two cycles of 30 impulses were delivered at 4 atm and an attempt to reinflate the balloon, there appeared to be contrast tracking toward the proximal RCA beyond the balloon margins under the previous stents.

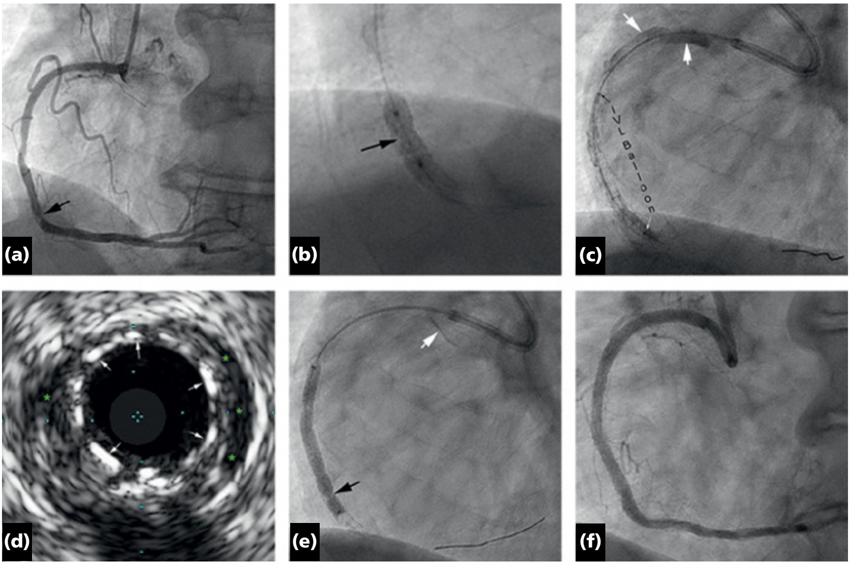

Figure 20.4 (a) Coronary angiogram of the RCA in LAO-Cranial projection with black arrow showing focal distal in-stent restenosis; (b) NC balloon inflations at 30 ATMs with arrow pointing to the dog boning artefact; (c) IVL balloon partially filled with contrast and contrast staining in the proximal segment of RCA behind the previously placed stents (white arrow); (d) IVUS of proximal RCA segment showing stent (white arrow) and intramural hematoma (green asterisk); (e) New IVL balloon with black arrow pointing to the ISR and white arrow pointing to contrast stain in the right coronary cusp (f) Final coronary angiogram after balloon angioplasty and new stent in the proximal-ostial RCA.

Video 20.13 IVUS performed that revealed an intramural hematoma behind the stented segment in the mid- and proximal segment of the RCA.

Video 20.14 Further IVL was performed with a new balloon.

Video 20.15 Final coronary angiogram after balloon angioplasty and new stent in the proximal-ostial RCA.

Confronting Adversities

*****IVL balloon rupture due to calcium nodule or inappropriate inflation** The balloon is designed to deliver shockwaves to the calcium in the vessel wall. Inflating the balloon to 4 atm is adequate to appose to the vessel wall. Sometimes, the balloon can rupture due to calcium nodules, which can act as a sharp blade to shear through the balloon. In case of balloon rupture, the chances of damage to the vessel wall are minimal due to low pressure and the presence of calcium. If the balloon ruptures, it can be carefully pulled out, and a new IVL balloon can be utilized to perform IVL.

*****IVL catheter fracture or balloon entrapment** Balloon entrapment is rare and can happen in inexperienced hands. The balloon might not completely deflate to its original state. The methods described are trial and error, which might be helpful in difficult situations.

*****Risk of coronary dissection/intramural hematoma** Risk of coronary dissection/intramural hematoma is low; however, the shear stress on the calcified plaque with resultant fracture, especially in deep calcium or compression force, can lead to calcified plaque spallation resulting in dissection/intramural hematoma.

TACTICAL TRICKS

1. Pull negative pressure on the indeflator to deflate the balloon entirely before attempting to remove it.
2. Push forward, as it helps remove attachments from the IVL balloon, and pull gently.
3. The balloon can be inflated further and try to treat the area further if you have remaining IVL therapy.
4. While inflating the balloon, advance the guide up to the balloon and deflate it to pull in the guide. Be careful with the presence of a lesion proximal to the treated area before this maneuver, as it can cause lesion disruption from guide injury.
5. In case a balloon gets stuck, and the above maneuvers do not work, another wire can be positioned alongside to the IVL balloon as buddy wire, acting as a rail to pull the IVL balloon, or a small 1.5 balloon can be loaded on the buddy wire and inflated beside the IVL wire to free it from attachment.
6. In case a balloon gets stuck, and the above maneuvers do not work, the catheter shaft can be cut to advance a guide extension catheter, which can facilitate the removal of the IVL balloon.
7. If a guide extension catheter was used, advance it to the balloon end, slowly pull it into the guide extension catheter, and remove the whole system.
8. Different snares can be used to retrieve the fragmented catheter in case of a catheter shaft break. It is always better to capture as distally as possible, closer to the balloon.

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CHAPTER 21

Venous Interventions

Mihas Kodenchery, Ajoe John Kattoor, Trai H. Nguyen, and Uyen Truc Gia Dang

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CHALLENGES

One in five adults has significant chronic venous disease and would benefit from either lifestyle changes or intervention. Non-thrombotic venous diseases do not have significant mortality; however, they contribute to significant morbidity, limiting lifestyle and functional capacity, as well as causing a significant loss of productivity. It is a slow progressing disease, and early intervention with exercise, weight loss, stocking, and interventional procedures can halt the progression of the chronic effects of the disease. Early application of compression should be performed to avoid swelling and progressive scarring and to initiate the healing process by improving venous microcirculation.

Physiology of venous return The heart pumps blood to the feet, while the calf muscles are responsible for venous return. If the valves of the superficial and deep veins, as well as perforators, are competent, contraction of the calf muscles associated with walking leads to effective venous return to the heart and maintains a low ambulatory venous pressure (Figure 21.1). Incompetence of the valves in the superficial, deep system, or perforators leads to reflux of deep venous blood into the superficial and distal veins. This results in inefficient venous return and a progressive increase in ambulatory venous pressure.

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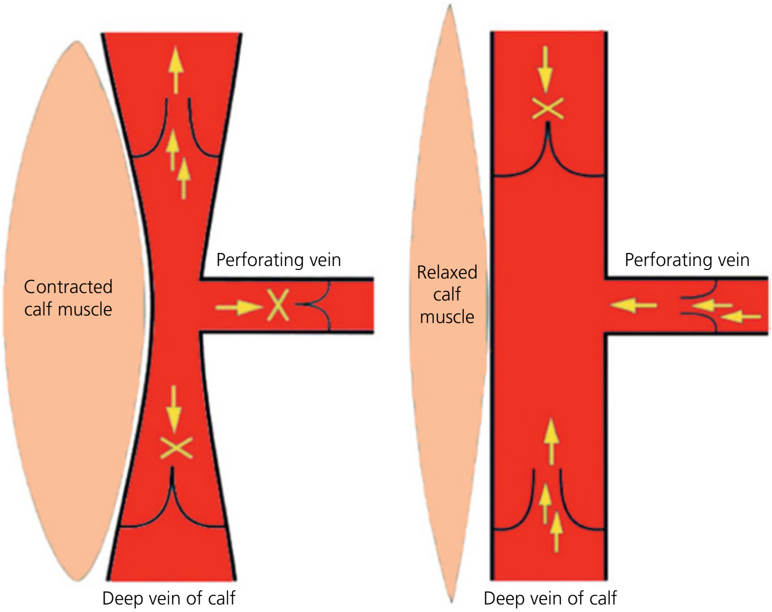

Figure 21.1 Physiological mechanism of venous return.

GAME PLAN

Assessment of severity of chronic venous disease To standardize the reporting and treatment of the diverse manifestations of chronic venous disorders, a comprehensive classification system (CEAP) was developed to allow uniform diagnosis and comparison of patient populations. The fundamentals of the CEAP classification include a description of the clinical class (C) based on objective signs, the etiology (E), the anatomical (A) distribution of reflux and obstruction in the superficial, deep, and perforating veins, and the underlying pathophysiology (P), whether due to reflux or obstruction.

Classes C0 to C6 with specific signs:
C0: No visible or palpable signs of venous disease
C1: Telangiectasis (spider veins) or reticular veins
C2: Varicose veins
C3: Edema
C4: Skin changes (pigmentation, eczema, induration)
C5: Healed venous ulcer
C6: Active venous ulcer
Etiology: congenital, primary, or secondary to deep vein thrombosis
Anatomical location of the disease: superficial vein, deep vein, or perforators
Pathophysiology: Reflux or obstruction

Pathophysiology of chronic venous disease In addition to primary reflux disease, in a significant proportion of patients, insufficiency of superficial veins or perforators results from obstruction or reflux in the deep venous system. It should be suspected when severe venous disease is present in the absence of superficial venous reflux or when the severity and clinical

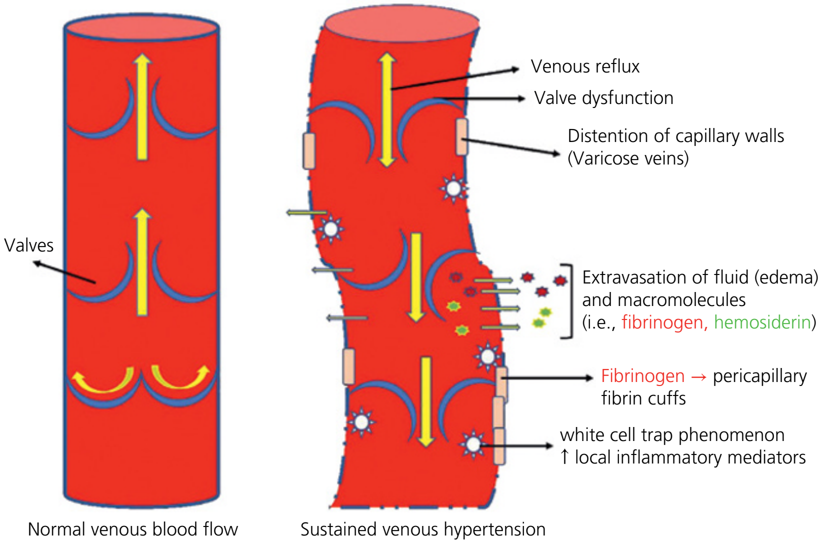
Venous reflux
Valve dysfunction
Distention of capillary walls (Varicose veins)
Valves
Extravasation of fluid (edema) and macromolecules (i.e., fibrinogen, hemosiderin)
Fibrinogen → pericapillary fibrin cuffs
white cell trap phenomenon ↑ local inflammatory mediators
Normal venous blood flow
Sustained venous hypertension

Figure 21.2 Pathophysiology of venous disease.

manifestation of venous disease are disproportionate to the degree and level of reflux on venous insufficiency studies. Venography with intravascular ultrasound guidance and venous stenting can be performed if obstruction is associated with improved clinical outcomes. As venous disease progresses, ambulatory venous pressure increases, and the clinical severity of venous disease advances from edema to spider veins to venous ulcers (Figure 21.2).

Venous obstructions There are three primary causes of venous obstructions: non-thrombotic iliac vein lesions (NIVL), acute deep vein thrombosis, and post-thrombotic iliac vein lesions. Other rare causes include benign or malignant tumors, retroperitoneal fibrosis, atresia of the IVC, iatrogenic injury, radiation exposure, cysts, and aneurysms.

Non-thrombotic iliac vein lesions Arterial compression of iliac veins with secondary fibrosis, bands, or webs can lead to recurrent thrombosis, poor resolution, and recanalization of thrombus, as well as post-thrombotic perivenous fibrosis. Eighty percent of iliofemoral deep vein thrombosis (DVT) is associated with underlying NIVL and should be considered in all patients with leg edema and pain not responding to conservative therapy (Figure 21.3).

Diagnostic imaging CT venography and MR venography are useful for identifying anatomy at risk for NIVL (more useful in post-thrombotic surveillance). Hemodynamic assessment across iliac vein compression and stenosis is unreliable; usually, a 2–5 mm gradient can cause severe symptoms. Venography alone can miss 50% of NIVL. Venography with intravascular ultrasound is the most reliable test for diagnosing NIVL. Intravascular ultrasound assessment of the vein showing evidence of more than 50% area is considered significant, and stenting is associated with significant clinical improvement (Video 21.1).

Video 21.1 Left iliac venogram demonstrating abnormal haziness in the left iliac vein with critical stenosis.

In some cases, pelvic vein compression or stenosis is not easily evident, and secondary telltale signs of obstruction must be considered: intraluminal webs and chords, partially canalized thrombus distally, perivenous fibrosis, pre-stenotic dilation (Figure 21.4), stasis in distal veins as evidenced by significant Rouleaux formation, and underfilled inferior vena cava (IVC).

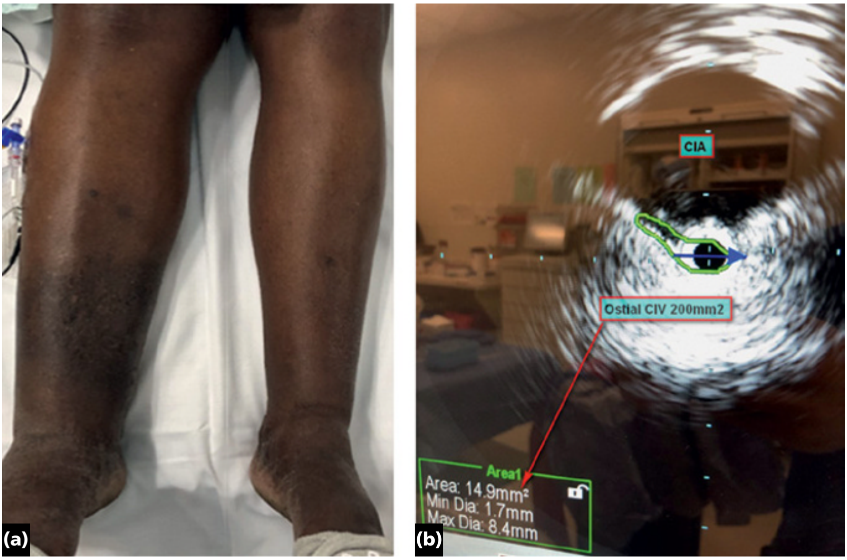
(a)
(b)
CIA
Ostial CIV 200mm2
Area1
Area: 14.9mm²
Min Dia: 1.7mm
Max Dia: 8.4mm

Figure 21.3 Common locations of Non thrombotic Iliac vein lesions (NIVL).

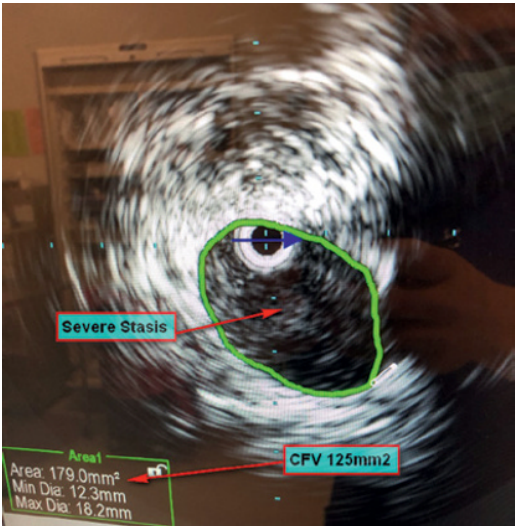
Severe Stasis
CFV 125mm2
Area1
Area: 179.0mm²
Min Dia: 12.3mm
Max Dia: 18.2mm

Figure 21.4 Intravascular ultrasound demonstrating pre-stenotic dilation of common femoral vein (CFV) and stasis

CRITICAL THINKING

When do a venogram?

Consider venogram in the following clinical scenarios:

- Nonhealing venous ulcer, lymphedema, lipodermatosclerosis
- Severe venous disease unexplained by reflux
- Severe venous disease or varicosities not responding or recurrence after ablation
- Severe unexplained persistent edema beyond ankle joint
- Acute proximal DVT (iliofemoral DVT), DVT involving confluence of vein or CFV (75% of CFV DVT have associated iliac DVT)
- Symptomatic DVT after 2 weeks of anticoagulation suggests defective inflow
- Chronic deep vein thrombophlebitis after 6 months of anticoagulation
- Severe post-thrombo-phlebitic syndrome
- Recurrent DVT and suspected anatomic abnormalities to outflow
- Venous claudication
- Unexplained persistent leg pain with good arterial flow
- Swollen leg, blue leg, purple legs, severe varicosity above knee joint
- Suspected pelvic congestion syndrome

PATIENT SELECTION

There is no role for treating NIVL in asymptomatic patients as it is a permissive condition for chronic venous disease. An additional insult such as reflux, thrombosis, trauma, cellulitis, secondary lymphatic exhaustion, or immobilization can lead to clinical manifestations such as edema, pain, ulcers, claudication, or stasis dermatitis. Approximately 75% of patients will respond to treatment of the permissive condition by stenting the venous obstruction.

ARTERIAL STENTING VERSUS VENOUS STENTING

In arterial stenting procedures, the aim is to establish good downstream perfusion. It is customary to slightly under-correct stenotic lesions ("perfect is the enemy of good") to avoid dissection or rupture. The aim of venous stenting is to relieve upstream back pressure. This is best achieved by achieving the largest absolute cross-sectional area that can be safely achieved. The goal is to use the largest stents that can safely be deployed to achieve post-stent areas mirroring normal anatomy. The basis of symptoms in chronic venous disease is elevated peripheral ambulatory venous pressure. Ambulatory venous pressure begins to rise with as low as 20% stenosis in large veins and becomes clinically significant at 50% venous stenosis. Percentage venous stenosis is calculated based on anatomic minimums: common iliac vein – diameter 16 mm, area 200 mm^2; external iliac vein – diameter 14 mm, area 150 mm^2; common femoral vein – diameter 12 mm, area 125 mm^2.

The aim of venous intervention is to achieve a post-stenting area as close to the anatomic minimum as possible with a smooth transition to inflow and outflow. Commonly used stent sizes for the common iliac vein are 16–18 mm, for the external iliac vein are 14–16 mm, and for the common femoral vein are 12–14 mm. Undersizing stents in iliac veins can result in residual symptoms, even though the stent may remain patent (Figure 21.5).

Clinical Outcomes after Venous Stenting

- Improvement in pain: 74% of limbs (cumulative) experienced improvement, with complete relief in 65% at 5 years.
- Improvement in swelling: 62% of limbs showed improvement, with complete relief in 32% at 5 years.
- Healing of ulcers: Achieved in 58% of cases at 5 years.

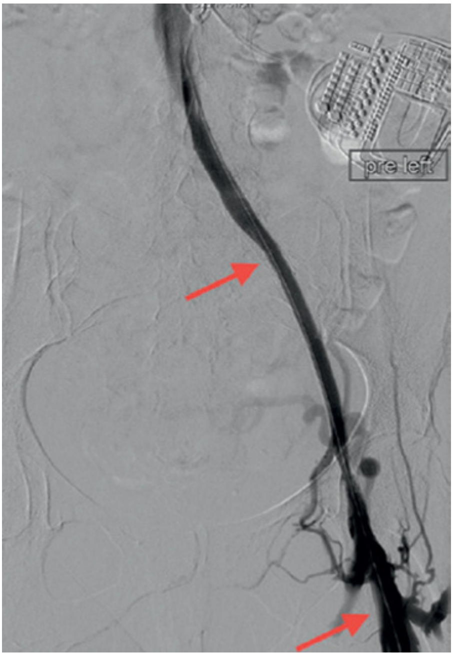

Figure 21.5 Venogram demonstrating pre-stenotic dilation in femoral vein due to undersized 8mm stent in iliac vein, though patent, in a patient with persistent symptoms

Due to the ease of percutaneous technique and acceptable safety and efficacy, iliac vein stenting is the preferred approach in most patients with advanced disease, including the frail and elderly population.

VENOUS STENTING TECHNIQUE

The patient is positioned in the frog position in the cath lab, where the hip is flexed, and the thigh is abducted and externally rotated (Figure 21.6 and Figure 21.7). The preferred access point is in the greater saphenous vein below the level of the lesser trochanter. Another option is the superficial femoral vein in the mid-thigh. Accessing the superficial femoral vein in the thigh requires careful maneuvering under ultrasound guidance to avoid the superficial femoral artery. Accidental access to the superficial femoral artery must be avoided as it is located in a noncompressible site. Self-expanding braided stainless-steel stents are preferred.

In contrast to the management of peripheral arterial disease, where stenting of the common femoral artery is avoided, venous compression and stenosis often extend into the common femoral vein. Therefore, it is common practice to extend the stent into the infra-inguinal portion of the common femoral vein (Figure 21.8). Stenting across the saphenofemoral junction and the bifurcation of the common femoral vein into the superficial femoral vein and deep femoral vein should be avoided.

Ostial iliac stenosis near the confluence of iliac veins poses challenges in treatment. Extending the stent into the IVC is often done to compensate for early caudal migration and to prevent geographical miss of the ostial lesion. However, extending the stenting too much into the inferior vena cava can result in jailing of the contralateral iliac vein and increases the risk of contralateral iliac vein thrombosis. Therefore, it is crucial to avoid geographical miss of the

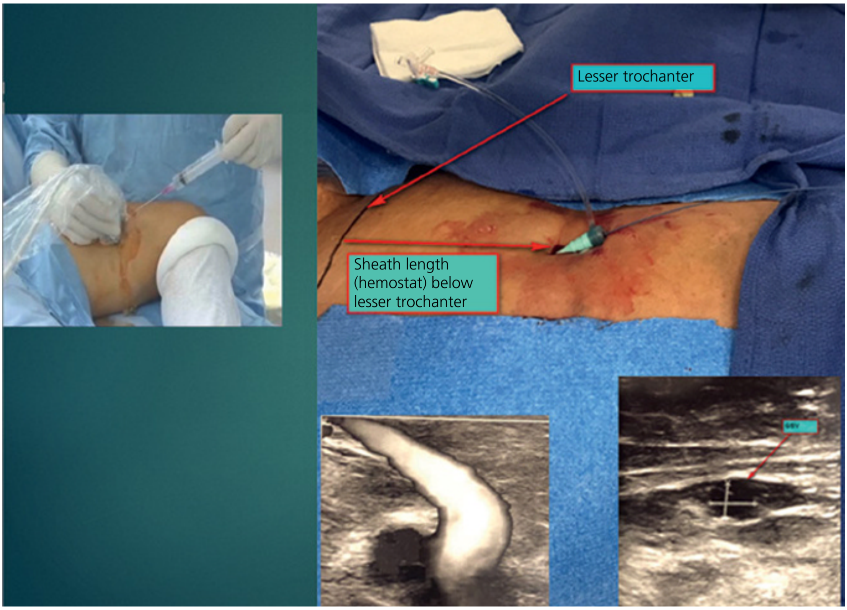
Lesser trochanter
Sheath length (hemostat) below lesser trochanter
GSV

Figure 21.6 Demonstration of venous access for intervention. Patient is positioned in frog position. Lesser trochanter is marked under fluoroscopy. Using ultrasound guidance, the greater saphenous vein is accessed in the mid-thigh.

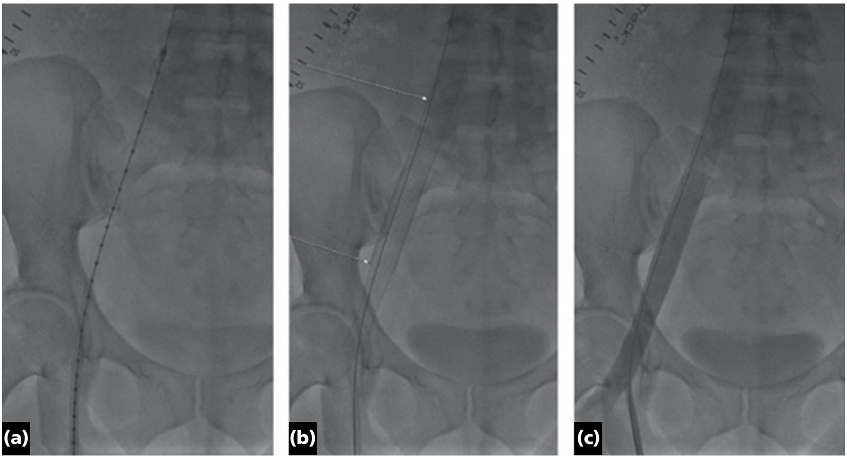

Figure 21.7 Panel a - Performance of Venogram and IVUS through sheath in greater saphenous vein access; Panel b – Placement of sheath in greater saphenous vein allows it to be pulled back for stent deployment into the common femoral vein; Panel c - The venogram through the sheath in the greater saphenous vein reveals the iliac stent extending into the common femoral vein, yet halting just above the saphenofemoral junction.

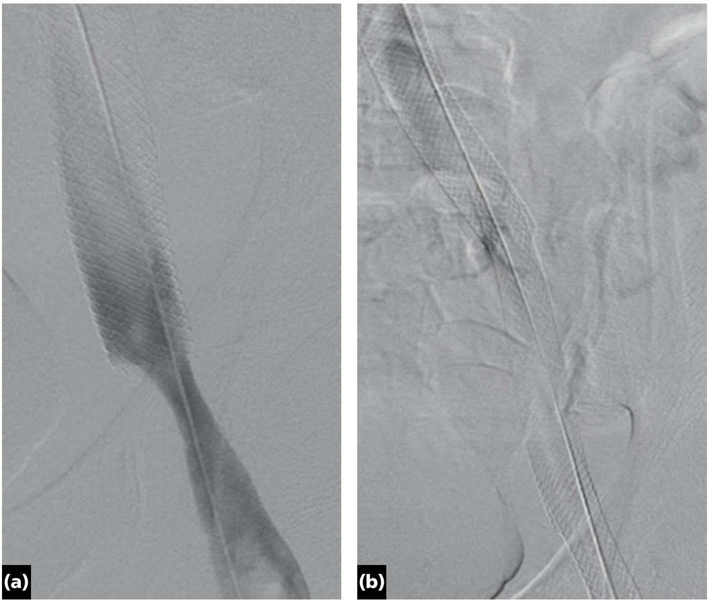

Figure 21.8 Panel a – Venogram demonstrating poor Inflow at the landing of stent, thereby increasing the risk of stent thrombosis; Panel b – Fluoroscopy demonstrating poor transition between stents, increasing risk of in-stent restenosis and thrombosis.

ostium to prevent symptom recurrence. Placing the stent too close to the lesion can lead to coning, which is associated with a high risk of DVT. Simultaneous double-barrel stenting into the IVC is a better strategy in true ostial iliac vein stenosis to prevent missing of the ostium and to protect the contralateral iliac vein (Video 21.2).

Video 21.2 Double barrel stenting of common iliac into the IVC.

Undersized stent placement can lead to persistent symptoms, stent thrombosis, and deep vein thrombosis. It also increases the risk of stent embolization. Oversized stents can lead to stent erosion and an increased risk of perforation. When multiple stents are deployed, it is imperative to ensure a smooth transition between the stent and the inflow and outflow (Figure 21.8). A floating stent in the inflow can lead to stent thrombosis, while a floating stent in the outflow can lead to embolization.

Veins are usually forgiving, but heavily fibrotic lesions, oversized balloon, and high-pressure angioplasty can result in venous perforation. Prolonged low-pressure angioplasty, reversal of anticoagulation, and covered stents are options to treat such unanticipated complications.

Intervention in Venous Thromboembolic Disease

The role of intervention in deep vein thrombosis includes proximal iliofemoral DVT, persistent symptoms despite anticoagulation and lifestyle changes, and post-thrombophlebitis syndrome (Figure 21.9). Possible options include catheter-directed thrombolytic therapy and mechanical thrombectomy devices.

Majority of DVTs occur in lower extremities. DVT in unusual sites are always secondary to underlying mechanical causes or hypercoagulable disorders.

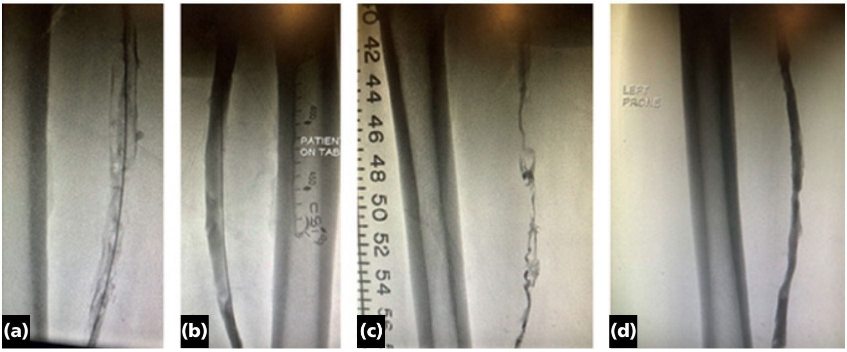

Figure 21.9 Panel a & b – Acute iliofemoral DVT Pre (a) and Post (b) thrombolysis. Panel c & d – Subacute Iliofemoral thrombosis with microchannel Pre (c) and Post (d) intervention.

Post-intervention Care

After venous interventions, different protocols are implemented based on the access site and the nature of the intervention. For access through the great saphenous vein (GSV), purse-string sutures are typically applied, which are removed within 2 hours post-procedure. Patients are discharged at 3 hours after ambulation. Similarly, access through the common femoral vein (CFV) can also use purse-string sutures, which can be removed 4 hours post-procedure. Patients are discharged 6 hours post-procedure after ambulation. Post-thrombotic interventions necessitate full-dose anticoagulation and removal of purse-string sutures the next day, with ambulation permitted after 1 hour. However, caution is advised regarding ambulation with groin purse-string sutures in place due to the heightened risk of vasovagal episodes. Access through the popliteal vein follows a similar protocol with purse-string sutures, full-dose anticoagulation, suture removal the next day, and ambulation after 1 hour. For post-stenting in non-thrombotic venous disease, patients may receive dual antiplatelet therapy for 30 days, followed by aspirin alone. In contrast, post-thrombotic intervention calls for non-vitamin K antagonist oral anticoagulants (NOACs) and dual antiplatelet therapy for 30 days, with NOACs continued thereafter or administered alone. Alternatively, patients may receive enoxaparin for 14 days, followed by NOACs for ongoing therapy.

COMPLICATIONS

High pressure angioplasty was performed to treat fibrotic ring lesion to subclavian vein leading to perforation. The perforation did not seal with prolonged ballooning and reversal of anticoagulation. Finally, attained hemostasis with IVUS guided covered stent (Videos 21.3 and 21.4).

Video 21.3 Subclavian vein thrombosis as a complication of Paget Schroetter disease.

Video 21.4 High pressure angioplasty was performed to treat fibrotic ring lesion to subclavian vein leading to perforation. The perforation did not seal with prolonged ballooning and reversal of anticoagulation. Finally, attained hemostasis with IVUS guided covered stent.

CHAPTER 22

Carotid Artery Occlusive Disease

Gianluca Rigatelli and Giuseppe Marchese

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CHALLENGES

Most carotid artery disease is due to atherosclerosis from hypercholesterolemia. However, other rare pathologies can also cause symptomatic carotid artery disease. They are fibromuscular dysplasia (FMD), spontaneous cervical dissection, and acute aortic dissection extending to the carotid arteries.

Fibromuscular Dysplasia

Fibromuscular dysplasia is a nonatherosclerotic, noninflammatory vascular disease characterized by stenosis due to thickening of the arterial wall [1]. Carotid FMD is most commonly encountered in middle-aged women, who may be symptomatic or asymptomatic. Clinical manifestations may include stroke, transient ischemic attack, carotid dissection, Horner syndrome, cranial nerve palsies, or subarachnoid hemorrhage. The pathophysiology and natural history are unknown. Gross pathological manifestations include elongation, kinking, and coiling of the carotid artery, spontaneous dissection, and aneurysmal degeneration. Antiplatelet therapy is generally recommended even for asymptomatic patients. Both surgical revascularization and endovascular approaches have been successful in alleviating ischemic symptoms in patients with FMD of the carotid arteries.

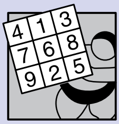
Spontaneous Cervical Dissection

Spontaneous carotid artery dissection is a nontraumatic tear in the wall of the internal carotid arteries or the vertebral arteries, not a rare event in young patients of both genders (25% of strokes in patients <45 years of age) [2]. Dissection results from an intimal tear that initiates an intramural hematoma. Subintimal dissection tends to cause stenosis, whereas subadventitial dissection can result in aneurysmal degeneration. A number of pathological associations have been described, most of which involve connective tissue disorders. In 90% of cases, there are local signs and symptoms of carotid territory ischemia on the side of the dissection, but in 10% of patients the dissection is asymptomatic. Head, facial, or neck pain and pulsatile tinnitus are the most frequent symptoms. Urgent magnetic resonance imaging (MRI) and computed tomography angiography (CTA) are warranted to define the diagnosis when an ischemic stroke is preceded by these symptoms and signs.

Acute Aortic Dissection Extending to the Carotid Arteries

This occurrence usually causes a sudden onset of excruciating, ripping pain. Ascending aortic dissections tend to manifest with pain in the midline of the anterior chest, whereas descending aortic dissections manifest with pain in the back. Aortic dissections usually occur in the presence of risk factors including hypertension, pregnancy, atherosclerosis, and other conditions that lead to degeneration of the aortic media, such as Marfan and Ehlers–Danlos syndromes. In cases of retrograde extension of the dissection flap to the common carotid arteries, these symptoms precede the cerebral ischemic syndrome. In a known aortic dissection involving the ascending aorta, new cerebral ischemic events mean extension of the dissection with the need for surgical intervention [3].

GAME PLAN



The current treatment of carotid artery stenosis includes smoking cessation, inhibition of platelets by aspirin, lowering cholesterol level with statin therapy, and pharmacological treatment of hypertension and diabetes, if present. Variation in this treatment includes the additional use of ticlopidine, clopidogrel, or warfarin [4]. The contraindications to carotid stenting are listed in Table 22.1.

All patients were on dual antiplatelet therapy (aspirin 100 mg and clopidogrel 75 mg/day) for at least 3 days before the intervention and for 4 weeks afterwards. All procedures were performed by two experienced interventional cardiologists who had previously received dedicated and proctored training for peripheral and carotid interventions.

Revascularization procedures were performed via the transfemoral (in the majority of patients) or transradial approach under local anesthesia, with systemic heparinization and with 6- to 10-Fr introducers. As CTA was not routinely performed before the procedure, aortic arch digital subtraction angiography was systematically performed with 10 mL of contrast media to evaluate anatomical variants and to plan the most suitable carotid access technique.

The pre- and postprocedural checklist for carotid procedures is listed in Table 22.2. For a center starting a carotid program in particular, it is highly recommended that all these evaluations should be performed before doing the procedure. Of course, it is essential that the diagnostic tests listed in Table 22.2 are repeated after the procedure.

Table 22.1 **Contraindications to carotid stenting**

Anatomical contraindications

- Severely tortuous, calcified, and atheromatous aortic arch vessels (Type III aortic arch)
- Severe kinking and tortuosity of the femoro-iliac arteries and no viable brachial/radial arteries
- Pedunculated thrombus at the lesion site

Clinical contraindications

- Severe renal impairment precluding safe use of contrast agents
- Patients contraindications to antiplatelet agents

Table 22.2 Pre- and Postprocedural checklist for carotid procedures

1. Adequate medical and neurological evaluation
2. CT scan or MRI of the brain to document preprocedural anatomical deficits
3. A formal neurological assessment and completion of a National Institutes of Health (NIH) stroke scale pre- and postprocedure
4. Some operators still recommend a complete cerebral angiography in a separate examination or immediately before carotid angioplasty and stenting. However, with the availability of MRI, angiography seems to be less important. In our center, a four-vessel angiography is rarely performed
5. Duplex ultrasound pre- and post-stenting to exclude fresh thrombus and as a baseline for follow-up
   Aspirin 300 or 325 mg and clopidogrel (Plavix) 75 mg once a day. Different from coronary interventions, the goal is not so much to avoid thrombus formation after stent implantation but to avoid fresh thrombus prior to stent implantation. This fresh thrombus may embolize during the procedure. Therefore, the treatment with aspirin and clopidogrel should start at least one week before.

GAME PLAN

Step 1: Vascular access The femoral access approach is the most commonly used with a 4- or 5-Fr sheath. In complex anatomy, or when it is planned to choose a proximal cerebral protection system, a standard 5- to 8-Fr 12-cm arterial sheath is used. In cases of diseased iliac arteries, a 23-cm sheath may be used, and in cases of abdominal aortic aneurysm, a 40-cm sheath may be preferred. The patient is given heparin to obtain an activated clotting time (ACT) of 200–250 seconds.

Step 2: Aortogram A 5-Fr pigtail catheter is advanced into the ascending aorta over a standard 0.035-inch wire. After angiography of the aortic arch and recognition of the anatomy, a roadmap can be obtained to facilitate the advancement of a 5-Fr internal mammary artery or Judkins Right (JR) into the common carotid artery (CCA). Prior to cannulation of the common carotid, careful aspiration and a flush of saline should be performed to clear any debris or thrombus.

Step 3a: Cannulation of the carotid artery and selective angiography (long-sheath technique) Cannulate the CCA with a 5-Fr diagnostic catheter, usually with a right coronary or mammary catheter. Access the external carotid artery (ECA) with an angled hydrophilic wire and advance the diagnostic catheter into the ECA. Perform a digital angiogram (roadmapping) to display the origin of the ECA. Replace the current wire with an exchange length 0.035-inch wire. Generally, a stiff Amplatz-type wire should be used. The diagnostic catheter is then exchanged over the wire for a 6-Fr 90-cm sheath that is advanced into the CCA below the bifurcation. Gently manipulate the sheath during engagement because it can cause a tear at the ostium of the CCA or dislodge atherosclerotic debris. Aspirate and flush meticulously so that there is no air inside.

Step 3b: Cannulation of the carotid artery and selective angiography (guide catheter technique) We prefer to use the no-touch technique in order to minimize the risk of embolism or dissection of the CCA. Over a standard 0.035-inch wire, an 8-Fr multipurpose (MP) guide is carefully advanced into the aortic arch over the previously obtained roadmap. Then, a 0.035-inch hydrophilic wire is advanced into the guide until its proximal tip exits from the guide. Manipulate the guide with gentle rotation to engage the

CCA. “Back bleed” and flush carefully, and take a “guiding” image lesion by injecting through the sheath. Arteriography is performed in an angulation that best shows the opening of the bifurcation and pinpoints the severity of the stenosis. During the intervention, the most useful projection is not only the one showing the maximum stenosis, but also those separating the internal and external carotid arteries and those showing the bony landmarks.

Step 4: Angiography of intracranial vessels Perform angiography of intracranial vessels in two projections: lateral and anteroposterior 30° cranial. These angiograms will be very important for comparison and further intracranial rescue procedures in case of cerebral embolization during intervention.

Step 5: Cerebral protection Distal embolization is the major cause of complications during carotid stenting. Therefore, we use cerebral protection devices in all patients. They are described in more detail later in this chapter. Generally, the device has to be introduced and placed distal (filter or occlusion balloon) or proximal (occlusion balloon) to the lesion.

Step 6: Predilatation Predilatation is done to facilitate the introduction of the stent delivery system in cases of very tight or calcified carotid artery stenosis. A 2- or 3-mm monorail or coaxial angioplasty balloon is advanced to the lesion over the 0.014-inch wire, which is attached to the filter or distal occlusion balloon, or over a separate 0.014-inch wire if a proximal occlusion balloon is used for cerebral protection. For predilatation, a coronary angioplasty balloon is inflated at low pressures. On very rare occasions (very tight and calcified lesions), predilatation has to be performed even before the introduction of a cerebral protection device. Give atropine (1 mg intravenously) 2–3 minutes before balloon inflation to prevent bradycardia.

Step 7: Self-expandable stent deployment Exchange the balloon system for a stent system. The diameter of the stent should be 1–2 mm larger than the largest carotid segment to be covered. Most often, stents with a diameter between 6 mm (if the stent is implanted into the internal carotid artery [ICA] only) and 10 mm are used. Although the ICA is 2–3 mm smaller than the CCA, oversizing the stent in the ICA does not cause problems. Covering the ECA is safe and rarely causes occlusion of the ECA. The stent should be long enough to cover the lesion completely, usually 3 or 4 cm long.

Step 8: Post-stenting management After stent deployment, balloon dilatation should be done at nominal pressure, watching carefully for bradycardia and hypotension. Give atropine (1 mg intravenously) 1–2 minutes before balloon inflation to prevent bradycardia. The balloon diameter should be equal to the diameter of the ICA distal to the stent. Post-stent dilatation of the stent segment in the CCA is not necessary and not recommended. If the ECA becomes significantly stenosed or occluded, this does not cause symptoms and does not need treatment. Perform angiography to identify further lesions, dissections, and embolic complications.

Step 9: Removal of the cerebral protection device Almost all currently available filter devices are removed with a retrieval catheter. Where an occlusion balloon has been used, the debris in the ICA has to be aspirated before occlusion balloon deflation and retrieval (at least two 20-mL syringes using the MO.MA™ device). Perform carotid angiography, including intracranial branches, to document the final result and to exclude distal embolization.

General Measures

Continuous monitoring of the heart rate, blood pressure, and neurological status throughout and after the intervention is mandatory. Good hydration and maintenance of an appropriate blood pressure are important in the recovery period. At the time of balloon inflation, the blood pressure always goes down, so there is no need to lower the blood pressure beforehand, even if the patient is severely hypertensive. After the procedure, the systolic blood pressure should be below 140 mmHg. A lower pressure is preferable, especially in cases of a very tight lesion before stenting and/or in cases of a contralateral occlusion, because these patients have a higher risk of intracranial bleeding. The sheath is removed when the ACT is less than 180 seconds.

VASCULAR ACCESS

The standard approach is the femoral approach; however, nowadays the transradial and transulnar approaches are gaining as alternative and more comfortable approaches, while the direct cervical and transapical approaches are very rarely used unless other approaches are unfeasible.

Transradial/transulnar Approach

Puncture (radial artery or ulnar artery) is performed according to standard techniques. The ulnar artery provides a more straightforward route than the radial artery and can be used when the radial artery is considered too thin or tortuous to be catheterized. We prefer the right arm for both carotid arteries (right and left sides). A 5- or 6-Fr sheath is introduced. A unit composed of a 125-cm-long Simmons 1 catheter inserted within a Terumo 6-Fr 90-cm-long sheath (mother and child technique) is advanced into the subclavian artery through a Terumo soft wire. Cannulation of the right CCA is usually easy. Alternatively, a JR or a mammary artery guide can be used. After entering the ostium of the right CCA with the catheter, the wire is advanced into the ICA, and the entire unit is then advanced into the CCA, at the same time removing the catheter. The left CCA is usually accessed with a unit composed of the long sheath and a Simmons 2 or a radial bilateral Tilon catheter with the same technique. In a patient without elongation of the aortic arch, the angle between the right brachial artery and the right CCA is not suitable for the transbrachial approach, whereas in a patient with aortic arch elongation, the angle is often more favorable (Figure 22.1).

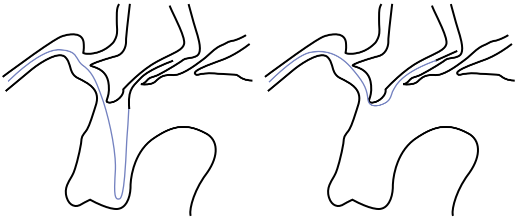


Figure 22.1 Entering the left common carotid artery from the right brachial approach: the left common carotid artery can be entered via the right brachial artery using a Sidewinder catheter [5].

TOP PERFORMANCE

Cervical Approach via Direct Puncture Technique

The patient is placed on the table with a cushion under the shoulders. The head is turned away from the side to be punctured. Duplex ultrasound should be used to locate and mark the carotid bifurcation. The best puncture site is located approximately 1.5–2 cm above the clavicle. The position of the needle tip in relation to the carotid bifurcation has to be checked with a contrast injection before any further steps are taken. If the position is correct, the needle is exchanged for a 5- or 6-Fr sheath over a 0.035-inch wire. After the procedure, the sheath is withdrawn, and gentle pressure must be applied for 10–15 minutes. Protamine should not be given.

Transapical Approach Technique

A patient presented with a "hostile" aortic arch, manifesting as unfolding of the thoracic aorta, an inferior angulation of the arch, and origin of the innominate artery at an acute angle from the ascending aorta. These factors precluded the advancement of a 10-Fr sheath into the innominate artery, despite several attempts. Neither a right brachial approach nor an open surgical approach was deemed an acceptable alternative. A transapical approach was considered a possibility in this case based on the reported experience of other centers with transapical aortic valve replacement. The angle of origin of the innominate artery from the ascending aorta made passage of the 10-Fr sheath into the right CCA fairly straightforward. Deployment of the covered stent was accomplished expediently and without difficulty over a 0.035-inch J wire [6].

GUIDES

GAME PLAN

The key is to advance the guide slowly over the wire while maintaining the wire deep inside the carotid artery. The left wall of the upper thoracic aorta can be used to support advancement of the guide into the carotid artery. One has to recognize "bad" and "good" curves of the guide within the aortic arch while advancing the guide. The guide is pushed over the wire slowly, also taking advantage of the pulsating blood flow. This maneuver, advancement of the guide and withdrawal of the wire, is made several times until the guide is securely placed in the artery. If there is a tortuosity of the proximal segment, the artery can be straightened with a wire. The guide can also be rotated while being advanced, clockwise or counterclockwise, depending on the curve formation in the aortic arch. Asking the patient to take a deep breath helps to elongate and thus straighten the great vessels. During that short window of opportunity, the guide is moved further. Another important aspect is to gently "ease back" on the guide curve in the arch as successive wires are advanced. This reduces the curve in the arch and prevents the successively stiffer wires from prolapsing the guide down into the ascending aorta. Excessive manipulation of the guide in the arch may predispose to distal embolization.

Tips and Tricks

***Cannulation of the brachiocephalic arteries from the femoral approach** A 5-Fr JR or left mammary artery guide is usually preferred. Guides with a similar shape are the Headhunter H1 and the Bentson–Hanafee–Wilson JB1 guide. This type of guide is advanced over the aortic arch over a hydrophilic 0.035-inch wire. This avoids trauma to the intima of the aortic arch and prevents the guide tip from becoming trapped by vessel ostia. In the ascending aorta, the guide is turned around 180°, which places the tip in a vertical upright position. Thereafter, the guide is gently pulled back. Usually this motion will bring the guide tip into the brachiocephalic artery. If the left CCA is the target, the guide should be pulled further distally very slowly. During this period, the guide should be turned 20° counterclockwise to make the tip point slightly anteriorly. This helps to engage the left CCA. To stabilize the guide in the left CCA, it is necessary to rotate the guide 20° clockwise to make the tip of the guide point vertically or slightly posteriorly again.

If we are not successful with one of these guides, we usually switch to a Simmons/Sidewinder guide. This guide forms a loop in the ascending aorta. By pulling back the guide, the tip engages the vessels of the aortic arch (brachiocephalic trunk first). In contrast, with the Vitek guide, a loop is formed in the descending aorta. A catheter with a similar shape is the Mani guide. By pushing the guide toward the ascending aorta, the tip engages the left subclavian artery, the left CCA, and finally the brachiocephalic trunk.

****Technique of engagement of the right carotid artery from the femoral approach** Usually engagement of the right carotid artery is accomplished by advancing the guide in the right subclavian artery and rotating it counterclockwise to engage the ostium of the right CCA. If catheterization of the ICA is desired, the head is again turned to the contralateral side; however, the neck is flexed to align the ICA with the CCA. The tip of the guide is now pointed posteriorly, and the wire is inserted. The guide is advanced over the wire, and its tip is placed at the level of C2. It is important not to advance the catheter further, because this may cause spasm. In cases of a cervical carotid loop, the guide is placed below the loop (Figure 22.2) [7].

****Why a guide fails to advance through a tortuous artery** One major problem is failure to advance the guide into the carotid artery. Persistent forward movement of the guide will cause a loop to form in the aorta or the guide tip to flip back into the aorta (Figure 22.3). The physical and mechanical mechanisms of these problems are discussed in the following paragraphs and in Table 22.3. These mechanisms and their solutions can be applied universally

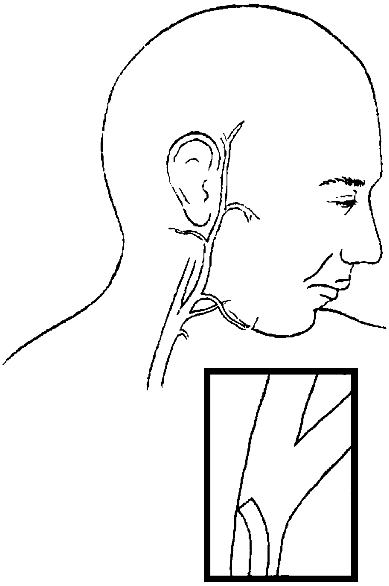


Figure 22.2 Catheterization of the internal carotid artery. The neck is flexed. This maneuver brings the internal carotid artery in line with the common carotid artery. Note the position of the tip of the catheter, which is pointed posteriorly (inset). Source: Adapted from [5].

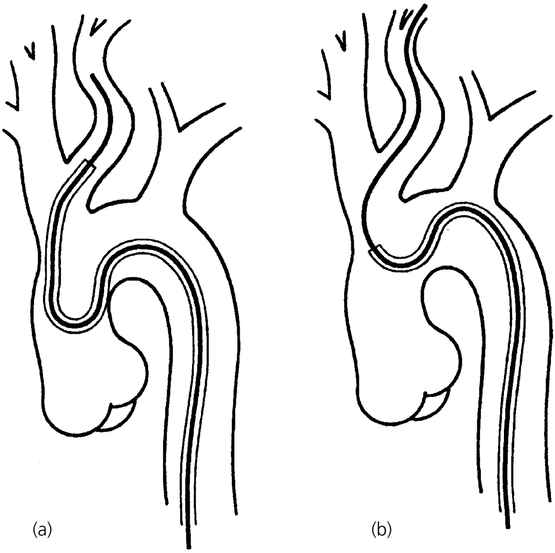


Figure 22.3 Difficulty in advancing the catheter over the guidewire. (a) The catheter forms a loop in the aorta. (b) The tip of the catheter flips back into the aorta. Source: Adapted from [5].

Table 22.3 Strategies for advancing a guide

Mechanism	Strategies
Lack of support by the wire	To use a stiffer wire (Terumo stiff, Supracor, Amplatz, etc.)
Excessively angled carotid origin	To use a stiffer wire or multiwire technique
Friction of the wire within the catheter	To advance the catheter while withdrawing the wire
Excessive distal curve of the catheter	To rotate while advancing the catheter

during instrumentation of any vascular bed, including the coronary, carotid, or renal arteries or their anomalies. The example illustrations are based on an anomaly of the left CCA.

To solve the problem of a weak platform created by a floppy wire, the wire has to be advanced further so the stiff segment is in the proper area. If the wire is not strong enough, it needs to be exchanged for a stiffer one [5].

To solve the problem of an acute angle at the origin of the artery, a stiff wire will straighten out the angle and help advance the guide.

To solve the problem caused by excessive friction between the wire and the internal surface of the catheter, the catheter should be advanced and the wire withdrawn simultaneously (Figure 22.4). This maneuver significantly reduces the friction between the wire and the internal surface of the catheter. Another way is to change the size of the wire to a smaller one, although this wire would not provide the same support as the previous wire; however, it would help advance the catheter if the problem were related primarily to friction rather than support [5].

To solve the problem of a sharp angle at the end of the catheter, while the wire is fixed, the catheter is advanced over it while rotating the catheter gently. The goal is to straighten the distal segment of the catheter by the wall of the artery so the catheter can adapt itself more to the angle and be advanced further (Figure 22.5).

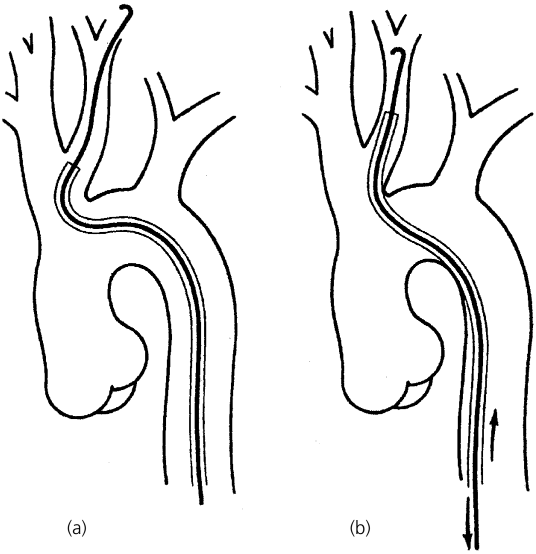


Figure 22.4 Diagram showing how to reduce the friction between the wire and the internal surface of the catheter. (a) The catheter tip is at the orifice of the left common carotid artery, and the tip of the wire is in the left internal carotid artery. (b) The catheter is advanced while the wire is withdrawn. Source: Adapted from [5].

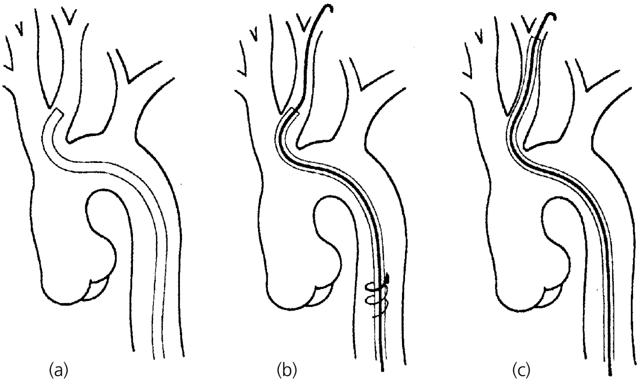


Figure 22.5 Straightening of the tip of the catheter by the wall of the artery. (a) The tip of the catheter is at the orifice of the left common carotid artery. (b) While the wire is fixed, the catheter is advanced over it using rotating forward movement. (c) The catheter has advanced over the wire into the vessel. Source: Adapted from [5].

In difficult situations, two or three of the previously mentioned maneuvers may be required before the tip of the catheter can be advanced to the desired level.

Using two 0.18-inch wires inserted in the same 5-Fr catheter instead of a standard or even stiff 0.035-inch wire is often a good way to increase support, while advancing the catheter at the same time diminishes the friction between the wire and the catheter and the wire and the vessel as well.

Failure to advance the guide usually includes different mechanisms related to angulation, excessive friction, or tortuosity. The main mechanisms and the relative corrective strategies are described in Table 22.3.

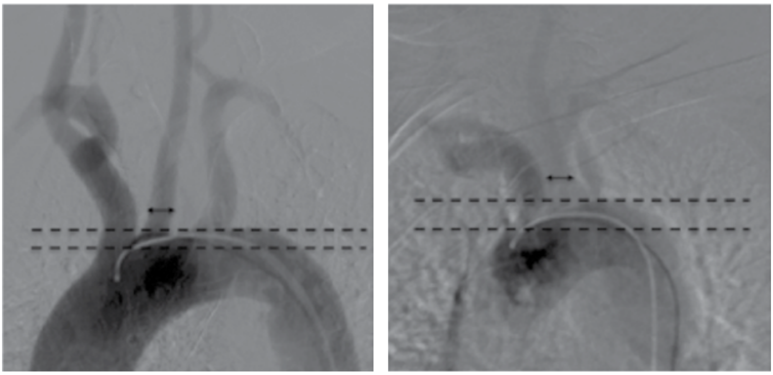
Aortic Arch Anatomical Variants

The aortic arch elongation variants are classified according to the vertical distance from the origin of the innominate artery to the top of the arch (Figure 22.6) [8]. The bovine arch variants are defined as follows [8, 9]:

- Bovine I: common origin of innominate artery and left CCA (Figure 22.7a)
- Bovine II: origin of the left CCA from the innominate artery (Figure 22.7b).

Tips and Tricks

****How to avoid complications** Careful procedure planning "tailored" to manage the individual aortic anatomy is suggested. In the presence of a low failure rate, procedure complexity may be measured by the parameters estimating resource utilization. Among these, the parameter that is theoretically more relevant for carotid artery stenting (CAS) safety is the duration of catheter manipulation. Catheter manipulation time (CMT) was defined as the time interval between the first angiogram depicting the aortic arch and the end of the procedure. CMT was similar in patients undergoing distal or proximal neuroprotection, whereas CMT differed significantly according to aortic elongation or bovine variants in both CAS with proximal and distal neuroprotection. It should be noted that, in the case of left ICA


Type I
Type II

Type III

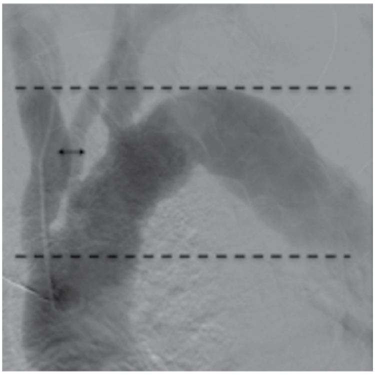


Figure 22.6 The images of patients with type I, type II, and type III aortic elongation variants. The arch is Type I if the distance is <1 diameter of the left common carotid artery (CCA). The arch is Type II if the distance is between 1 and 2 left CCA diameters. The arch is Type III if the distance is >2 left CCA diameters.

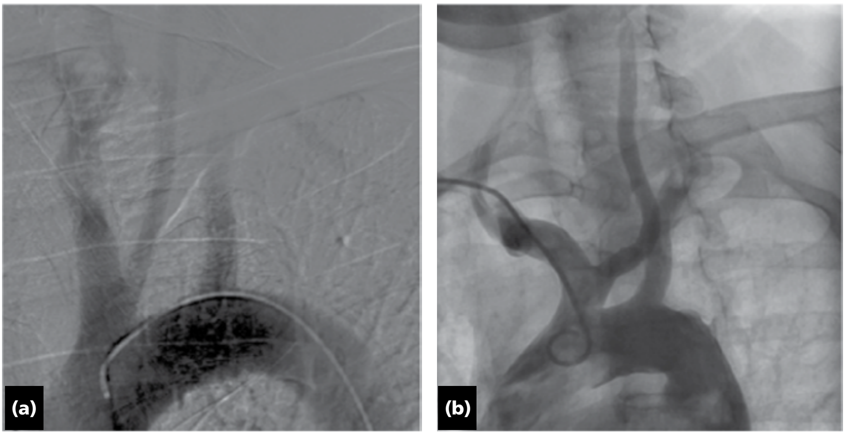


Figure 22.7 The images of patients with Type I (a) and Type II (b) bovine anatomy aortic variants.

CAS in patients with known bovine arch anatomies, a right-arm approach (in our series, via radial access) may be considered to shorten the operative time. CMT, but not complex anatomical features, was independently associated with 30-day clinical outcome. This finding supports the notion that catheter manipulation during CAS procedures is the main technical modulator of clinical outcomes and calls for careful procedure planning. Indeed, other anatomical aspects may combine with aortic arch anatomy to determine the overall procedure complexity.

*****Multiwire technique for hostile neck** Sometimes, especially in elderly patients with aortic arch type III or anomalous origin of the carotid arteries (bovine arch), it may be difficult to access severely tortuous, calcified arteries using the standard approach. In those arteries in which the wire will not advance without "kicking" the guide back, alternative strategies have to be considered.

In such cases, we prefer to use the so-called multiwire technique. The hostile neck is approached with a multiwire technique that includes, as a first step after aortic arch angiography, the cannulation of the CCA with a 5-Fr diagnostic left mammary artery catheter. With the aid of the roadmap technique and injection of 6 mL of contrast medium, the operator attempts to advance a 0.035-inch soft Terumo wire into the ECA. The catheter is then exchanged with an 8-Fr MP guide. If the first attempt to advance an 8-Fr MP guide to the distal CCA fails, a second and up to a third Terumo soft wire are advanced into the ECA in order to obtain advancement of the guide to the ICA (Figure 22.8).

*****Carotid access in the presence of occluded ECA, CCA lesion below bifurcation, or ostial CCA lesion** Placing a 7-Fr 90-cm access sheath into the CCA may present special challenges when the ECA is occluded, a critical lesion is situated below the bifurcation, or there is a critical ostial CCA lesion. If possible, avoid crossing the lesion with a stiff 0.038-inch wire because this is more likely to disrupt the necrotic plaque material and cause distal embolization. When possible, advance the 5-Fr diagnostic catheter over the 0.038-inch Glidewire to be placed more distally. In this situation, the Glidewire and 5-Fr catheter are first advanced through the lesion. This maneuver should be done only in

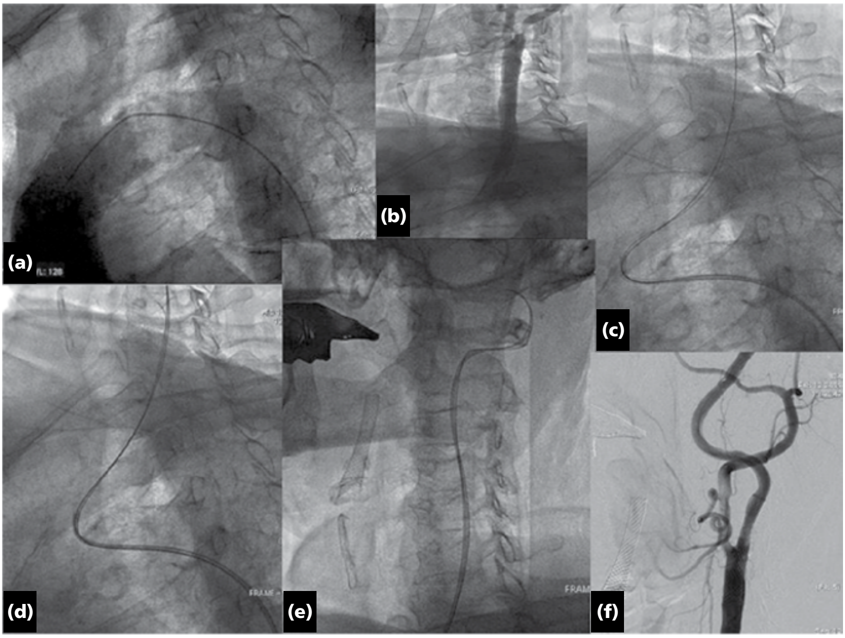


Figure 22.8 Multiwire techniques. (a) Aortic arch type III on aortography. (b) Carotid artery angiography with a 5-Fr diagnostic catheter. (c) Change of the diagnostic catheter for an 8-Fr multipurpose guide and subsequent advancement of three hydrophilic 0.035-inch wires in the external carotid artery. (d, e) Advancement of the guide over the three wires. (f) Success of carotid stenting and final result on angiography.

patients considered at high risk from carotid surgery if the risk:benefit ratio still favors stenting. In the presence of a carotid ostial lesion, the origin of the CCA should be dilated first to allow sheath access. The bifurcation should be stented first, and the ostium stented on the "way out."

ANGIOGRAPHY

After the guide enters the artery, slow hand injection is done to confirm the position of the guide and to ensure that good blood flow is maintained and that there is no subintimal entry of the contrast agent. Injections of contrast agent into all brachiocephalic arteries should be done with small amounts of contrast (no more than 6 mL per injection, hand injection, or 3–6 mL/s). Larger volumes create a mixture of arterial, intermediate, and venous phases, thus obscuring early filling veins and other pathologies.

Some operators always perform four-vessel angiography to check collaterals for interventions and rescue when needed. We usually do not do this in order to avoid the additional risk, especially if magnetic resonance angiography (MRA) has previously been obtained. Of course, MRA does not provide information about the functional capacity of the intracranial collaterals. If the ICA provides collaterals to the contralateral system, balloon inflation with transient occlusion of the ICA can cause seizure. On the other hand, stenting would still be possible.

Table 22.4 Devices for protection against cerebral atheroembolization from the aorta, arch, and great vessels

Type of device	Device	Manufacturer
Deflecting devices	Embrella	Edwards Lifesciences Inc., Irvine, CA
	Keystone Embolic Protection Device	Keystone Heart Ltd., Herzliya, Israel
Dual-filter retrieval	Sentinel™ Cerebral Protection System	Claret Medical Inc., Santa Rosa, CA
Aortic capture retrieval	Emblok™ embolic protection system	Innovative Cardiovascular Solutions LLC, Kalamazoo, MI

Table 22.5 Embolic protection devices for carotid artery stenting

Type of embolic protection device	Device	Manufacturer
Proximal occlusion		
With flow reversal	Gore neuroprotection system	WL Gore & Associates, Flagstaff, AZ
Without flow reversal	MO.MA Ultra	Invatec Inc., Bethlehem, PA
Distal filter	Emboshield NAV-6	Abbott Vascular Inc., Santa Clara, CA
	SpiderFX	ev3 Endovascular Inc., Plymouth, MN
	FilterWire EZ	Boston Scientific, Marlborough, MA
	RX Accunet	Abbott Vascular Inc., Santa Clara, CA
	FiberNet®	Invatec Inc., Bethlehem, PA
	Angioguard RX	Cordis Corporation, Fremont, CA
Distal occlusion	GuardWire®	Medtronic Inc., Minneapolis, MN

PROTECTION DEVICES

A major limitation of CAS is distal embolization. Balloon dilatation, stent implantation, and manipulation of the guide and wires release embolic debris, which can cause cerebral ischemic events. To prevent this usually catastrophic event and to improve the overall results, two different kinds of systems are used: devices for protection against cerebral atheroembolization from the aorta, arch, and great vessels (Table 22.4), and embolic protection devices for CAS (Table 22.5).

Filter Devices

Different filter devices usually have a similar mechanism of protection. Generally, a filter basket made of various membrane materials is attached at a fixed distance to the distal tip of a standard 0.014-inch wire. The undeployed filter device is manipulated to cross the lesion and opened distally at the carotid siphon. The commonly used devices are listed in Table 22.4 and shown in Figures 22.9 to 22.11.

EQUIPMENT

Angioguard XP™/Angioguard RX™

The Angioguard filter (Figure 22.9) consists of a parachute-type filter mounted on a 300- or 180-cm-long 0.014-inch wire, a delivery catheter, and a retrieval catheter. The monorail version using the short wire is preferred by most interventionalists. The filter comes in diameters between 4 and 8 mm and is compatible with vessels between 3.5 and 7.5 mm. The filter membrane is made of polyurethane. The pores in the filter have a diameter of 100 μm. The filter has eight nitinol struts. Four of these struts have a radiopaque marker. The deployment sheath is a rapid-exchange system and has a crossing profile of 3.2–3.9 Fr.

FilterWire EX/EZ™

This filter (Figure 22.10) is mounted on a 0.014-inch wire by means of an eccentric nitinol wire loop. Due to this design, the entry of particles into the filter is not impeded by filter struts. The new version of this device (FilterWire EZ) has better vessel wall apposition than the former device. The membrane of the filter is made of polyurethane and has pores with a diameter of 110 μm. The delivery catheter has an outer diameter of 3.2 Fr. The filter comes in one size and adapts to vessels between 3.5 and 5.5 mm in diameter. It can be withdrawn with a retrieval catheter of 4.3 Fr or with any 0.018-inch compatible balloon catheter.

SpideRX

The SpideRX Vascular Filtration System (Figure 22.11) consists of a windsock-type filter basket made of a nitinol wire mesh. The design of this filter has some similarities with the E.P.I. filter. However, it comes in different sizes between 3 and 7 mm. At the entrance of the filter, there is a clasp to ensure better vessel wall apposition of the opening of the filter. After crossing the lesion with the wire, the delivery catheter of the system is introduced. The crossing profile of the delivery catheter is 3.2 Fr. The wire is removed, and the filter is advanced through the delivery catheter and placed distal to the stenosis.

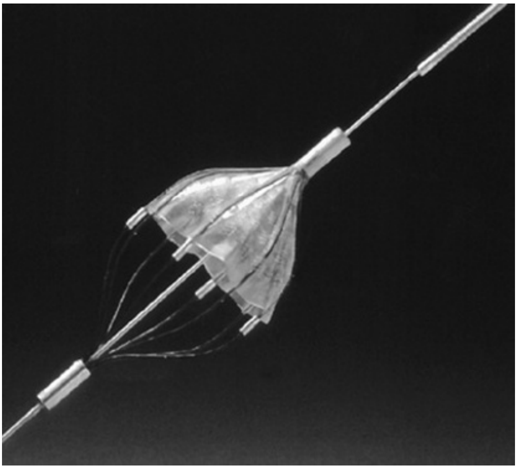


Figure 22.9 Angioguard filter device.

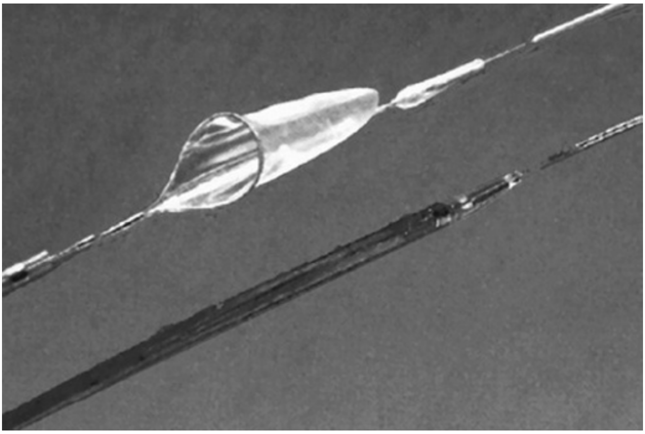


Figure 22.10 FilterWire device.

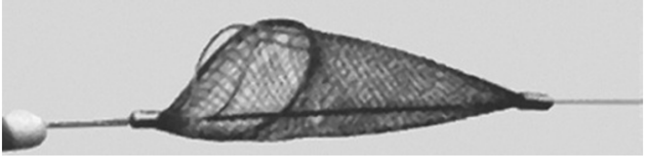


Figure 22.11 SpiderX device.

Occlusion Devices

Occlusion devices are based upon closure by means of a compliant balloon of the CCA and the ECA in order to establish retrograde flow in the ICA. Recently, the most commonly used system, the MO.MA device, has proved to be very effective, with a 30-day major stroke rate of 0.9% [7, 26]. The features of the commonly used systems are described in Table 22.5.

MO.MA

This device has some similarities with the Gore neuroprotection system. The occlusion balloon for the ECA is fixed to the guide (9-Fr), which allows faster and more reliable placement. This implies that the fixed distance between the balloon at the tip of the guide and the external occlusion balloon is suitable for the individual anatomy of the patient, which is the case in the majority. The distal balloon is capable of occluding vessels up to 6 mm (ECA), and the proximal up to 13 mm (CCA) (Figure 22.12). Instead of continuous retrograde flow to the venous system, aspiration with a syringe is used to remove the debris between the different steps of the procedure or at the end of the procedure. As with the Gore neuroprotection system device, angiography during the procedure is possible. The operator may use any kind of wire to cross the lesion, and in case of intolerance, the procedure can be performed stepwise.

Selection of the Protection System

A neuroprotection system should be selected according to anatomical and clinical criteria: fresh thrombus-containing lesions and absence of contralateral disease probably can be better managed by the use of an occlusion system, whereas in the presence of contralateral disease or occlusion, filter devices are probably preferable.

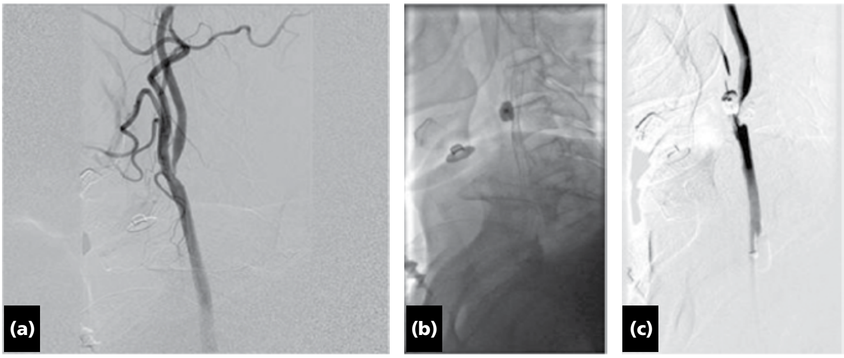


Figure 22.12 (a) Carotid lesion containing fresh thrombus. (b) Treated with MO.MA-assisted stenting. (c) Note the two inflated balloons in the common and external carotid artery.

BALLOON ANGIOPLASTY

Very tight or subocclusive carotid disease can be approached with gentle predilatation using a coronary 2.0, 2.5 or 3.0 × 20 or 30 mm balloon at nominal pressure, even in the presence of a thrombus-containing lesion. In such cases, a filter wire not fixed over a wire such as the SpideRX or, for very unstable lesions, a proximal occlusion system should be used if predilatation is necessary.

STENTS

Within the last few years, the number of carotid stents available has increased considerably, and major improvements have been made to meet the specific requirements of carotid stenting. During the first years of carotid stent implantation, balloon-expandable stents were mainly used. This technique had to be abandoned due to stent crushing that led to cerebral flow impairment. Since then, the interventionalist has been able to choose between self-expanding nitinol stents and stainless steel stents. Which stent to select depends on the arterial anatomy and the specific characteristics of the lesion. All nitinol stents are constructed from a nitinol tube that is laser cut. Depending on the number of bridges between the different rings, nitinol stents can be classified into those with a closed-cell or an open-cell configuration. The main features of commonly used stents are described in Table 22.6.

Discriminating Differences

In very tortuous access vessels, a low crossing profile of the delivery catheter is important. At present, the crossing profile does not differ significantly between the different stents.

In tortuous lesions a flexible stent is required to avoid straightening of the vessel and kinking of the artery at the end of the stent. Stents with a high flexibility are open-cell nitinol stents. The Wallstent™ delivery system currently has the highest flexibility.

To accomplish an even smoother transition between the ICA and CCA, tapered stents have been developed, characterized by a smaller stent diameter at the distal end of the stent. All currently available stents provide these features.

To treat severely calcified lesions, a stent with a high radial force is recommended. In general, closed-cell design stents have a higher radial force. Closed-cell stents provide better scaffolding to treat lesions with high emboligenic potential.

Table 22.6 Features of commonly used stents

Name	Stent material	Stent size (mm)	Foreshortening	Open cell	Flexibility
Carotid Wallstent	Stainless steel	6–10	Yes	No	Yes
Xact	Stainless steel	7–10	Yes	No	No
RX Acculink	Nitinol	5–10[a]	No	Yes	Yes
Sinus-Carotid	Nitinol	7–9[a]	No	Yes	Yes
Protégé RX	Nitinol	6–10[a]	No	Yes	Yes
Cristallo Ideale	Nitinol	7–11[a]	No	Yes	Yes
RoadSaver	Nitinol	5–10	No	Yes	Yes
Inspired MD C-Guard	Stainless steel	6–10	No	Yes	Yes

[a] Tapered.

EQUIPMENT

Carotid Wallstent

The Carotid Wallstent comes in a diameter of 6–10 mm and a length of 22–37 mm when fully opened. If the stent is implanted in a vessel, the length varies depending upon the degree of compression. This also means that the stent is much longer as long as it is fixed in the delivery system. During deployment, it foreshortens according to the diameter of the vessel. For example, a 31-mm-long stent with a diameter of 10 mm (fully open) is approximately 60–70 mm long while it is compressed in the delivery system. Implanted in a 9-mm vessel, it has a length of 40 mm. If it is implanted in an 8-mm vessel, it is 49 mm long.

It is a rapid-exchange system and compatible with a 0.014-inch wire. The outer diameter of the delivery system is 5 or 5.9 Fr, depending upon the diameter of the stent. The stent mesh design provides high plaque coverage. A disadvantage is that the stent straightens the vessel more than open-cell nitinol stents do.

Xact® Carotid Stent System

The Xact stent is a nitinol stent that comes in two different shapes. The straight stent is available in a diameter of 7–10 mm and a length of 20–30 mm, and the tapered stent in a diameter of 6–8 mm, 7–9 mm, and 8–10 mm and a length of 30 and 40 mm. It has a crossing profile of 5.7 Fr and a rapid exchange delivery system. The Xact stent has a closed-cell design, and therefore it is stiffer than other nitinol stents. It should be deployed only in straight vessel segments.

RX Acculink®

This open-cell nitinol stent is also available in two different shapes. The straight stent comes in a diameter of 5–10 mm and has a length of 20–40 mm, and the tapered stent has a diameter of 6–8 mm and 7–10 mm (length of 30 and 40 mm). The rapid exchange system is compatible with a 0.014-inch wire and a 6-Fr sheath.

Sinus-Carotid-RX/Conical RX

This nitinol stent is another stent that is available in two configurations. The straight stent has a diameter of 6–9 mm and a length of 20–40 mm. The tapered stent comes in a diameter of 6–9 and 7–10 mm and has a length of 30 or 40 mm. It has an open-cell design. The distal ends of the stent have higher radial force than the middle. A special feature is that the stent is attached to the 5-Fr delivery system until the very end of the release process, which prevents the stent from "jumping distally" during deployment.

Precise RX Nitinol Stent System

The Precise stent has a rapid exchange system with an outer diameter of 5–6 Fr. It is 0.014- and 0.018-inch wire compatible. The open-cell nitinol stent has a diameter of 5–10 mm and a length of 20–40 mm. This stent has high contour ability and flexibility.

Protégé RX®

This nitinol stent is available in a straight and a tapered design. The straight stent has a diameter of 6–10 mm and a length of 20–60 mm. The tapered stent has a diameter of 8–6 mm or 10–7 mm and a length of 30 or 40 mm. The stent does not shorten during implantation. The Exact Placement Release Technology avoids premature stent deployment.

Cristallo Ideale

This is a 5-Fr rapid exchange system. The straight stent has a diameter of 7, 9, or 11 mm and a length of 20–40 mm. The tapered stent comes in sizes of 7–10 and 6–9 mm with a length of 30 or 40 mm. It has a small cell size in the middle and a larger cell size (with more flexibility) at the proximal and distal ends.

Roadsaver®

This is a 5-Fr rapid exchange system based on a nickel–titanium double-layer micromesh design with a diameter ranging from 5 to 10 and a length ranging from 20 to 40 mm. The system has been designed to prevent plaque protrusion and emboli release after stent implantation. The double-layer micromesh has been created to contain plaque to the vessel wall. Thus it is very conformable to tortuous anatomy and is repositionable after 50% of the stent length has been deployed.

Inspired MD CGuard

The CGuard™ Embolic Prevention System is a mesh carotid stent based on an open-cell frame and the smallest mesh pore size. The system has been designed to prevent plaque protrusion and emboli release after stent implantation. It comes with diameters ranging from 6 to 10 mm and lengths of 20–60 mm [27].

POST-STENT DILATATION

It is safer to underdilate than overdilate the oversized self-expanding stents. Overdilatation squeezes atherosclerotic material through the stent mesh, causing emboli. A 10–15% remaining stenosis does not cause clinical problems. Importantly, it is not necessary to dilate the stent to obliterate segments of contrast-filled ulcerations external to the stent. This angiographic appearance is of no prognostic significance, and follow-up angiography has documented complete fibrotic healing of these lesions over time. Importantly, it is not necessary to overexpand the stent to produce a 0% residual diameter narrowing. Covering the ECA with a stent does not cause problems. If the ECA becomes occluded after postdilatation of the stent, this vessel can be approached through the stent mesh and reopened using coronary balloon techniques.

ADVANCED TECHNIQUES

**Aortic Dissection Extending to Carotid Artery

Acute aortic dissection is one of the most common catastrophes affecting the aorta. Aortic branch occlusion occurs in up to a third of patients with aortic dissection and is associated with increased risk of early death and serious complications. Surgery is the first-line therapy but has a high mortality and morbidity. Postoperative stroke is known to be an independent predictor of late mortality, and the best management for this complication is still debated. CAS before complete repair by means of surgery or stent-graft implantation can be a viable option in such cases. The use of protection devices may be problematic because of difficulty in defining the true and the false lumen, and probably they are not very useful because of the different nature and pathophysiology of the dissection in respect to atherosclerotic plaque. The trick is to advance the wire into the true lumen. In order to achieve this, careful evaluation of an aortogram and engagement of the carotid artery with a soft guidewire and small amount of contrast injection in order to check the correct position within the true lumen while advancing the guidewire is mandatory for success (Figures 22.13 and 22.14).

***Association between Severe Kinking and Occlusive Disease of the Carotid Artery

In the past, coiling or kinking of the distal ICA was considered a contraindication to CAS because it was thought to interfere with adequate distal embolic protection. However, studies have indicated that this finding does not influence CAS outcome and should not be considered as a contraindication to CAS. Moreover, sometimes new kinking or an increase of previously moderate kinking can occur after successful stenting of the ICA. If severe flow limitation does develop, implantation of a second stent may be considered an option: segmented nitinol stents improve the conformity between the prosthesis and vascular anatomy and should be considered the stent of choice in such cases (Figure 22.15).

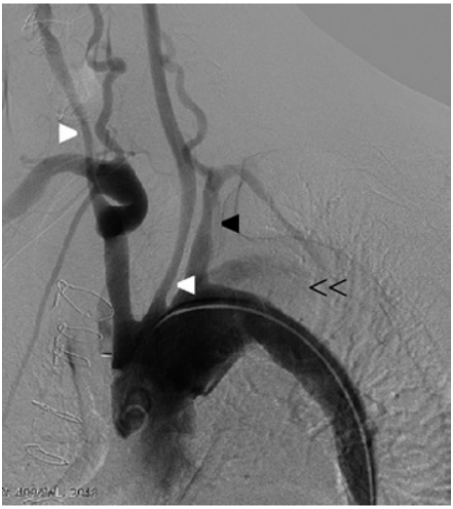


Figure 22.13 Aortic dissection extending to both the carotid arteries (arrows).

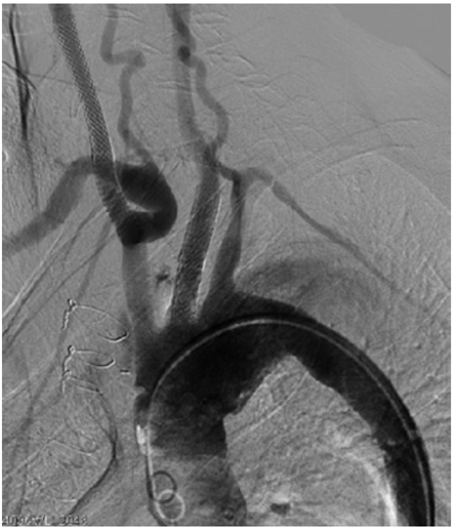


Figure 22.14 Successful stenting of the right internal and left common carotid arteries.

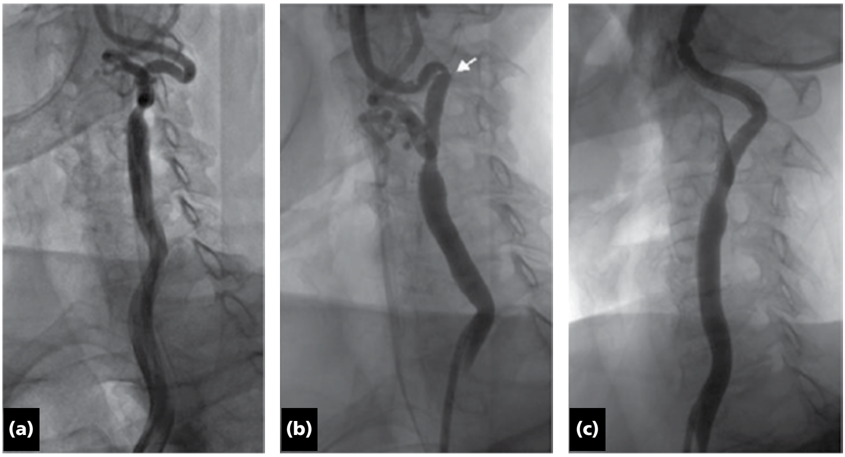


Figure 22.15 (a) Severe kinking and disease of the internal carotid artery. (b) After the first stent implantation, worsening of the previous kinking is noted with flow impairment. (c) A second nitinol stent fitting well to the vessel curve reestablished a good flow.

COMPLICATIONS

Thrombotic and Embolic Complications

Advantages of the endovascular approach over endarterectomy include the ability to immediately diagnose and treat these complications, and the patient can be awake, allowing close neurological monitoring. For acute thrombosis, local intra-arterial thrombolysis can be carried out using mechanical as well as chemical disruption of the clot. Extreme care must be exercised to avoid vessel perforation. Only very flexible microcatheters and soft wires may be used in the intracerebral circulation. Today cerebral protection devices are widely used and recommended by current guidelines, although a clear benefit has not been fully proved.

Carotid Artery Spasm

Wire-induced phenomena are minimized by the use of 0.014–0.018-inch wires. Carotid artery spasm can be successfully treated with nitroglycerin but usually disappears spontaneously.

Stent Restenosis

The restenosis rate for carotid stenting is less than 10% in most series [28]. Careful Doppler ultrasound evaluation should be performed in the follow-up, keeping in mind that velocity measurements are altered from the previous stent and the correlation between velocity and stenosis cannot be calculated in exactly the same way as for native stenosis. In doubtful cases, CTA or MRA can be performed. Rarely are there clinical indications to perform a redo percutaneous transluminal angioplasty. In such cases, balloon dilatation or an additional stent is required for treating a stenosis at the end of a stiff stent.

Carotid Perforation and Dissection

These complications are very rare and can occur after excessive balloon sizing prior to or after stent placement, especially in very tortuous or calcified arteries. If encountered, prolonged balloon inflation or even covered stents can be used if there is no compromise of major side branches in case of rupture, whereas additional stenting may be necessary to avoid flow disruption in cases of dissection (Figure 22.16).

Cerebral Hyperperfusion Syndrome

Hyperperfusion syndrome may be fatal once an intracranial hemorrhage occurs. Impaired cerebral autoregulation and post-revascularization changes in cerebral hemodynamics are the main mechanisms involved in the development of the syndrome, associated with a combination of excessive anticoagulation, uncontrolled hypertension, intracranial vessel manipulation, and stenting after a recent stroke (3 weeks) [29]. Terminate the procedure, reverse the anticoagulation, and control the hypertension. An emergency brain CT scan should be performed.

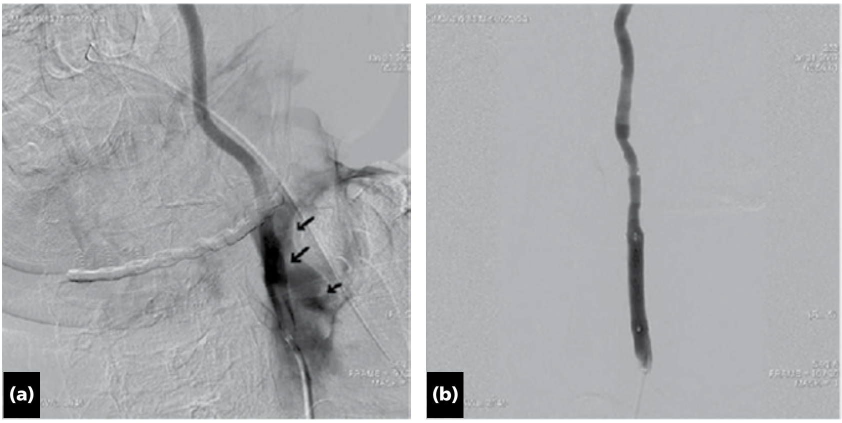


Figure 22.16 (a) Common carotid artery rupture during carotid artery stenting. (b) Result after stent graft implantation.

Operators should be familiar with the angiographic features of an intracranial mass effect. Sudden loss of consciousness preceded by a severe headache in the absence of intracranial vessel occlusion should alert the operator to this devastating event. Fortunately, with careful patient selection and compulsive attention to the above technical and anticoagulation issues, cerebral hemorrhage remains a very rare occurrence.

Cerebral Protection Device-Related Complications

Cerebral protection devices may also cause problems. All devices placed distally in the ICA may cause spasm or dissection. Rarely, additional balloon inflations and/or stent implantations have been necessary to solve the problem. It may be difficult to retrieve these devices through the implanted stent. It may occur that the filter is not fully opposed to the vessel wall. In contrast, the major disadvantage of occlusion devices is intolerance in patients with occlusion or high-grade stenosis of the contralateral ICA or patients with poorly developed intracranial collaterals. A specific disadvantage of occlusion devices is the need for a larger sheath, which may cause vascular access problems.

****Difficult retrieval of filter devices** Occasionally, because of vessel tortuosity and kinking and the angle created by the relative position of the stent within the vessel, retrieval of the filter device can be difficult. When the ICA above the stenosis appears tortuous and worsening of the preexisting kinking is likely, a guide–catheter technique and filters with an angled retrieval catheter, such as the FilterWire, or an occlusion device should be selected in order to retrieve the filter successfully with gentle manipulation of the guide or filter retrieval guide. Alternatively, when withdrawing the filter with the given guide is not possible due to the appearance of new kinking after stent placement, manipulating a diagnostic 4- or 5-Fr 135-cm JR or MP catheter inserted through the guide or the long sheath may change the angle between the stent and the filter and enable filter retrieval.

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CHAPTER 23

Iliac Artery Stenosis

Gianluca Rigatelli, Giuseppe Marchese, and Thoi H. Tran

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⧖, <10 min extra; ⧖⧖, >10 min extra
🌢, low risk of complications; 🌢🌢, high risk of complications

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CHALLENGES

Aortoiliac artery disease is a common presentation of atherosclerotic cardiovascular disease. Because of the high correlation between coronary artery disease and aortoiliac atherosclerosis, a global workup including coronary artery disease screening should be performed whenever possible [1]. With excellent results of angioplasty and stenting of the aortoiliac vessels, the endovascular approach has become the first-line therapy in the majority of these patients.

NONINVASIVE EVALUATION

Ankle/Brachial Index (ABI)

The new guidelines for peripheral artery disease (PAD) management divided patients into asymptomatic and symptomatic groups. For both groups, measurement of ABI is of paramount importance. An ABI of <0.90 is abnormal and highly suggestive of significant PAD. An exercise ABI might be helpful in asymptomatic patients with a high suspicion for PAD and a normal resting ABI (0.91–1.3) [2].

Treadmill Exercise Test with and Without ABI

Exercise testing may be extremely useful (1) in establishing the diagnosis of lower-extremity PAD when resting measures of the ABI are normal, (2) to objectively document the magnitude of symptom limitation in patients with lower-extremity PAD and claudication, (3) to objectively measure the functional improvement obtained in response to claudication interventions, (4) to differentiate claudication from pseudoclaudication in individuals with exertional leg symptoms, and (5) to provide objective data that can demonstrate the safety of exercise and to individualize exercise prescriptions in patients with claudication before initiation of a formal program of exercise training. Dedicated personnel and equipment are needed.

Ultrasound

Doppler ultrasound is useful to provide an accurate assessment of lower-extremity PAD location and severity, to follow lower-extremity PAD progression, and to provide quantitative follow-up after revascularization procedures. Unfortunately, in the aortoiliac segment, the efficacy of ultrasound is limited by the poor acoustic window of obese patients and the deep localization of the vessel in the abdomen.

Computed Tomography Angiography

Computed tomography angiography (CTA) requires intravenous injection of iodinated contrast, which opacifies the arteries. The angiographic image is constructed from multiple cross-sectional images and then presented as a maximum intensity projection, similar to the appearance of standard arteriography. The image can be rotated three dimensionally in space and be viewed in any projection. This is particularly useful in the aortoiliac segment, where Doppler ultrasound often is suboptimal because of technical difficulty.

Magnetic Resonance Angiography

Magnetic resonance angiography (MRA) of the extremities can be used to diagnose the anatomic location and degree of stenosis of PAD. MRA evaluation is based on imaging the arteries, similar to standard arteriography. Assessment of the accuracy of MRA depends on the MRA technique used and the standard against which it is compared. MRA techniques continue to evolve and improve. The techniques include two-dimensional time of flight, three-dimensional imaging, and contrast enhancement with gadolinium, subtraction, cardiac gating, and bolus chase. These techniques may be used in combination because each has its advantages and disadvantages. The technique is particularly useful in elderly patients with poor renal function but is limited by the presence of metallic prostheses and cardiac implants [2].

INVASIVE EVALUATION

Diagnostic Aortoiliac Angiography

Digital subtraction angiography (DSA) is the "gold standard" for defining both normal vascular anatomy and vascular pathology. It remains the most readily available and widely used imaging technique. Because of possible distal embolization or the effect of below-knee distal runoff on short- and long-term iliac stent patency, pre- and postprocedural lower-extremity angiograms should be done and compared against each other to assess for either of these complications [3].

Technique The usual technique includes the use of a 4- or 5-Fr pigtail catheter placed above the renal artery if flat panel radiological equipment is available or infrarenal if cardiac equipment is used [3]. Injection of 25–30 mL of contrast at 10–12 mL/s is usually sufficient with DSA to delineate the aortoiliac bifurcation and the external iliac arteries. The ipsilateral 20–30° oblique view can be selected in case of eccentric lesions. Pressure gradient measurement should be obtained with manual pullback to detect any significant stenosis >30 mmHg. Place a side-hole catheter at the level of L1–L2. Use the smallest contrast volume possible, especially when aortoiliac angiography is performed in conjunction with cardiac angiography and/or angiography of other vascular beds. Use the 20° contralateral angulation with 20° caudal angulation injection when a detailed relation between the internal/external iliac arteries is needed (Figure 23.1).

Intravascular Ultrasound

Intravascular ultrasound may be needed intraprocedurally when the severity of the lesion and its length are not easily measured or when ostial disease cannot be fully excluded: a 6-Fr peripheral intravascular catheter and sometimes, in cases of severely ectatic iliac arteries, a 9-Fr intracardiac ultrasound probe can be used [4, 5].

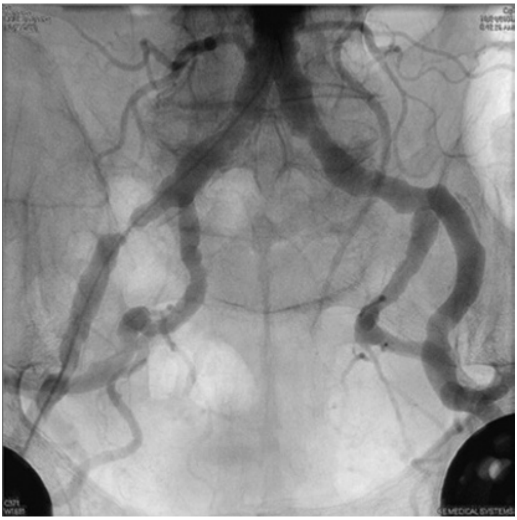

Figure 23.1 Aortoiliac angiography during coronary angiography in a 70-year-old patient with multivessel coronary artery disease.

STENTING TECHNIQUE

Access

Access is usually obtained from the ipsilateral femoral artery [6, 7]. Sometimes the contralateral approach is preferable, especially in cases of total occlusion without a nipple or when the ipsilateral femoral artery is itself diseased. Use whenever possible the ipsilateral approach. Select a 6- or 7-Fr sheath (at least 23 cm long). The longer sheath allows for sufficient contrast opacification and optimal visualization of the lesion through the sheath itself, even if injection is done retrogradely against systemic pressure. This often obviates the need for use of a contralateral pigtail catheter for positioning of balloons and stents (Figures 23.2 and 23.3).

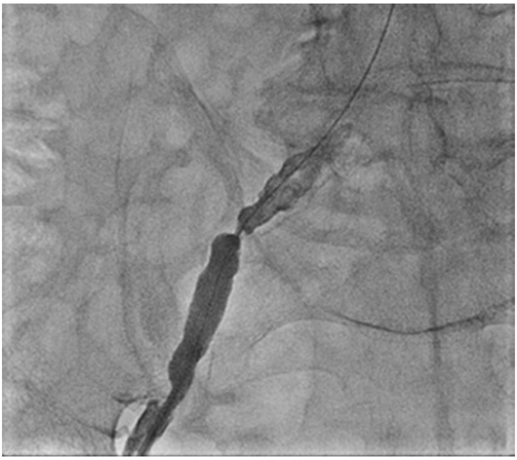

Figure 23.2 A 23-cm 7-Fr sheath has been placed through the femoral artery into the external iliac artery, and a preformable 0.035-inch soft-tip wire has been advanced through an external iliac artery tight stenosis.

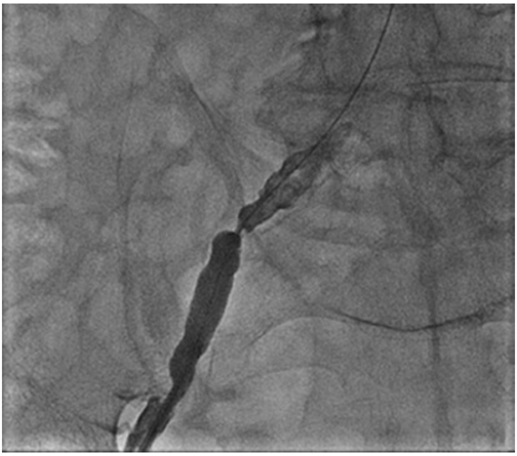

Figure 23.3 A small contrast injection through the 23-cm 7-Fr sheath visualized the tight stenosis; thus, a roadmap was created to allow for correct placement of a stent.

Wires

Wire selection is quite an important step. A 0.35-inch soft-tip performable wire may be used in most cases. Occasionally, an extremely tight stenosis will not allow passage of a 0.035-inch wire. In these cases, a 0.18-inch or, rarely, a 0.014-inch coronary high-support hydrophilic wire may be used to facilitate predilatation with small peripheral or even coronary balloons. Stiffer wires such as the 0.035-inch Supracor or Amplatz Super Stiff™ wires may be considered in cases where there is severe tortuosity, calcium, or stenosis that makes balloon passage difficult. In such cases it is useful to exchange the workhorse 0.035-inch wire for a stiff wire over a diagnostic 4-Fr Berenstein or multipurpose (MP) catheter.

When using a hydrophilic wire, one must pay careful attention to the tip. Follow the advancement of the tip under fluoroscopy to avoid access to an aberrant renal artery (with potentially severe renal damage). The wire tip is curved as a large C rather than a J. This shape is usually sufficient to cross the lesion without vessel damage but is also shaped in a way that it can inadvertently enter other aortic branches. Place the wire in the thoracic descending aorta, where there are fewer branches, to decrease the chance of the wire accidentally entering and damaging the arterial trees of other organs.

Balloons

For noncritically narrowed lesions, primary stenting is the usual technique of choice. However, sometimes predilatation is needed. In rare cases of a very tight stenosis or short occlusion, a 0.18-inch over-the-wire 4.0 × 40 mm balloon, or more rarely, a low-profile 0.014-inch monorail coronary balloon, 2.5–3.5 × 20–30 mm, inflated to nominal pressure would help to advance the stent. In all other cases, a normal peripheral 0.035-inch balloon, 4–6 × 20 or 30 mm, depending on the lesion length, can be used. Use of an indeflator to inflate balloons is recommended. Inflate slowly to 1 atm for 3–4 s and watch as the lesion is modified. Stop inflation if the patient complains of pain, as this could signify impending arterial injury or rupture. In general, undersizing the balloon by 1–2 mm will allow for adequate plaque modification even in calcified lesions, as the balloon can be inflated to over nominal pressure. This will not only facilitate stent passage across the lesion but also stent expansion during stent deployment.

Stent

Stent implantation is the current standard practice in iliac artery interventions. Proper stent selection is mandatory to achieve good immediate and long-term results. Focal calcified stenosis should be managed with a high radial force stent: 8–10 × 20–40 mm stainless steel balloon-expandable are the best option as well as for focal and ostial stenosis (Figure 23.4). The balloon-expandable stents allow precise implantation thanks to their excellent radio-opacity. They can be overexpanded with only minimal shortening. Long, diffuse, soft stenoses are better treated with 8–10 × 40–120 mm self-expandable nitinol stents: their open-cell design is preferred because of the low risk of distal embolization and optimal conformation to vessel anatomy (Figure 23.5).

Tips and Tricks

****Recommended stent positioning** Use a roadmapping technique when possible if balloon-expandable stenting is planned. Inject 5–8 mL of contrast, ensuring the iliac ostium is visualized, particularly if the ostium is to be covered. Position the balloon-expandable stent 2–3 mm beyond the iliac ostium in the abdominal aorta to assure full ostial coverage. Deploy the stent very slowly under fluoroscopy. If the stent moves during deployment, gently withdraw/advance the stent system as necessary, check position, and continue to slowly deploy the stent (Figures 23.6 to 23.8). An alternative technique is to advance the sheath over its dilator through the lesion within the distal abdominal aorta, take a picture with the roadmap technique, position the stent within the sheath, then withdraw the sheath while keeping the stent in place, and deploy the stent. If possible, avoid kissing stents with self-expandable stents: it can potentially be more difficult and cumbersome, and often the results are not satisfying [8].

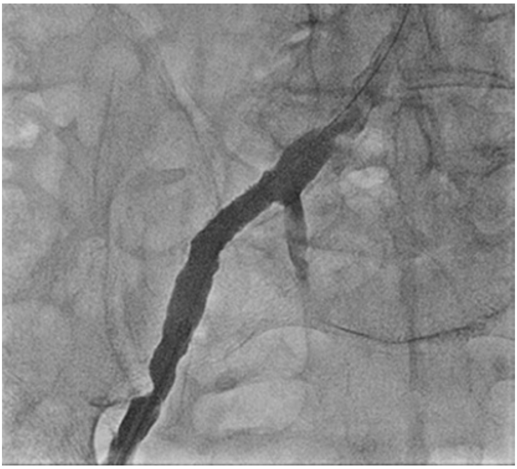

Figure 23.4 An 8 × 30 mm balloon-expandable stainless steel stent has been correctly placed with a good angiographic result.

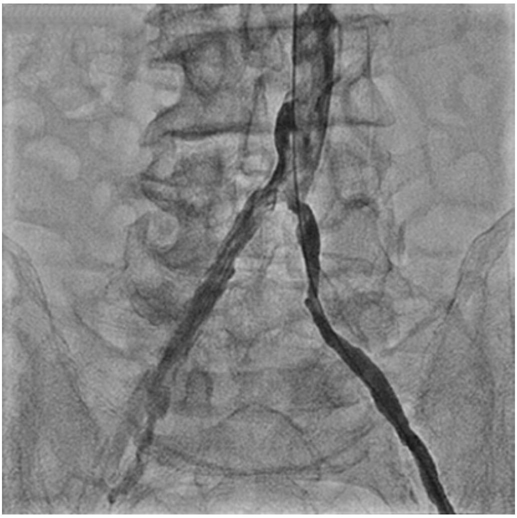

Figure 23.5 An aortogram during coronary angioplasty showed a long, diffuse stenosis of the left common iliac artery in a patient with multivessel coronary artery disease and 50 m claudication. The pressure gradient through the lesion was about 35 mmHg.

When performing a kissing stent technique, deploy the stents simultaneously with two indeflators at the same pressure (8–9 atm for most stents). Deflate the balloons, then advance both balloons beyond the distal end of the stent in the abdominal aorta and overdilate with high pressure (10–12 atm) to flare the ostial segments of the stents. This last maneuver should be done with care if there is a distal aortic lesion. For these cases, consideration should be given to positioning the kissing stents above the distal aortic lesion and including the lesion in the stenting. There should be little concern if 4–6 mm of the proximal end of the stent lies in the

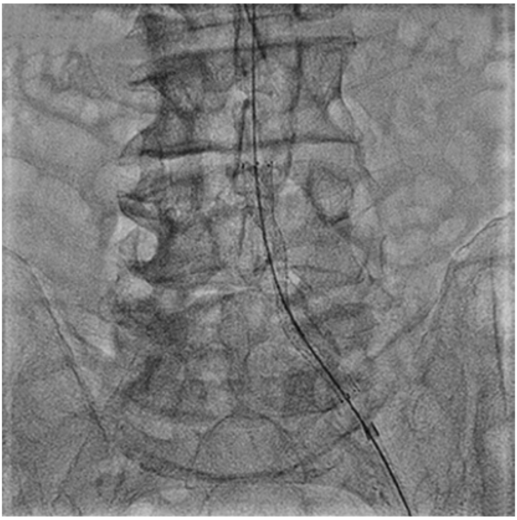

Figure 23.6 A self-expandable stent was deployed to cover the ostium and the entire lesion through a 7-Fr 23-cm sheath.

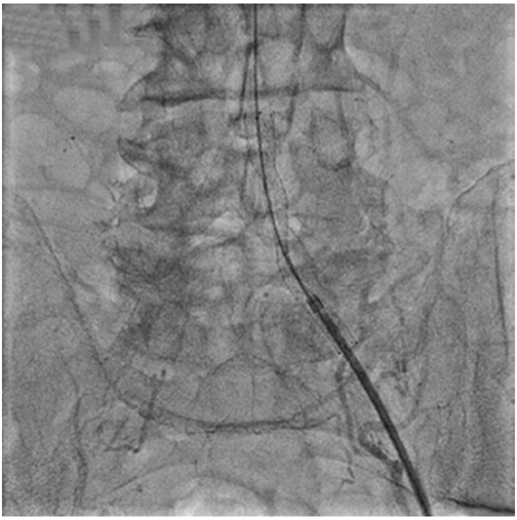

Figure 23.7 The sheath is gently advanced over its dilator into the stent to allow safe advancement of the balloon into the stent.

aorta: usually it is uneventful, and some operators even prefer it (Figures 23.9 to 23.11) [9]. This simply recreates the carina of the aortoiliac bifurcation cephalad to the original bifurcation point and should be of no clinical consequence. Check the final results carefully with an aortogram from a diagnostic pigtail catheter (with digital subtraction) technique to assess the results and any aortic damage. Alternatively, in bilateral kissing stents, simultaneous bilateral sheath injections would suffice.

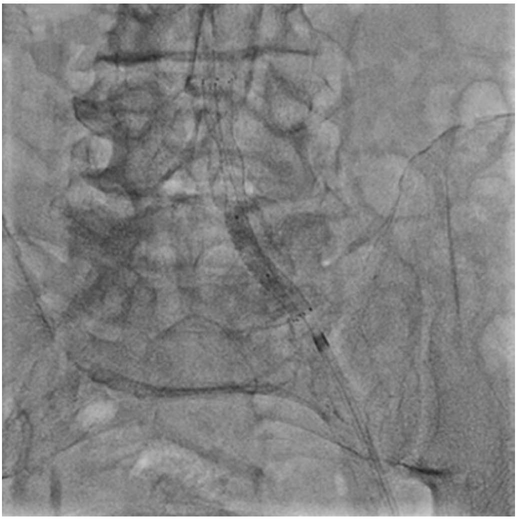

Figure 23.8 The balloon is slowly inflated at nominal pressure until the patient feels pain.

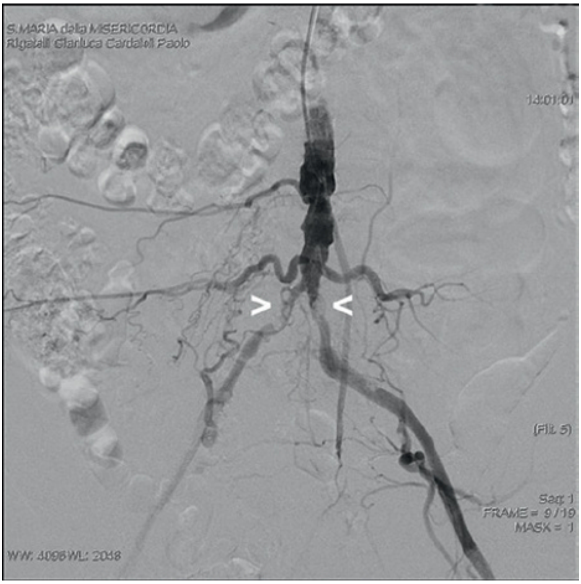
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Figure 23.9 Aortoiliac angiogram in 20° left anterior oblique projection showing severe aortoiliac occlusive disease (arrows).

****Brachial and/or radial access** Nowadays, the miniaturization of equipment and the availability of balloons and stents of a suitable shaft length allow for iliac stenting through a radial approach in simple cases [10, 11]. Brachial access may have the advantage of being able to accommodate larger sheaths and is more likely to be effective in reaching the aortoiliac

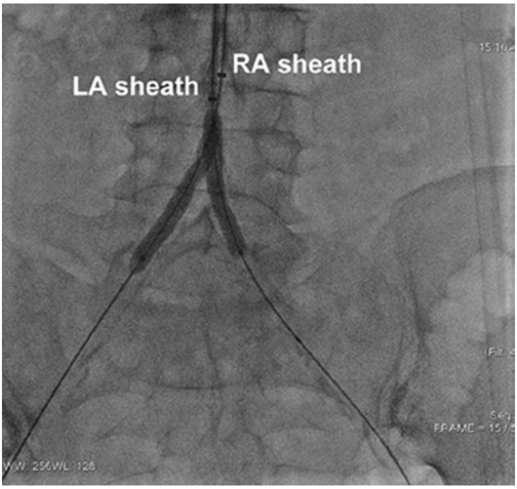

Figure 23.10 Kissing stenting with two 6.0 × 39 mm balloon-expandable stents through the long 6-Fr brachial sheaths.

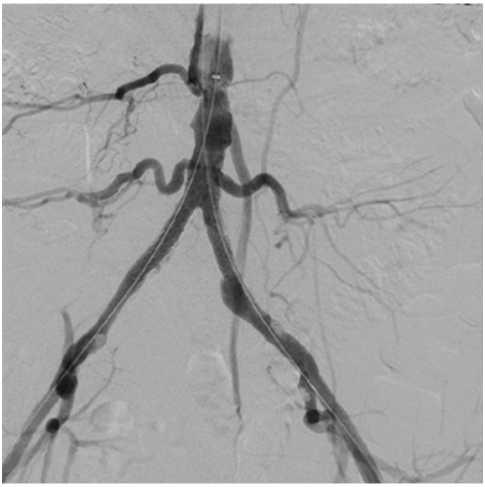

Figure 23.11 Final angiographic results after kissing stenting.

segment in tall patients, but the site access complication rate is higher compared to the radial approach. In cases of a severely calcified or tortuous aorta, passage of devices from the brachial/radial artery all the way down to the aortoiliac bifurcation can be facilitated by the use of stiff wires. Damage to the aorta can be avoided by passing the wire through a 4-Fr catheter and replacing the catheter with a long sheath (~85 cm). In addition to added safety, this technique offers more support than using two different guides, reduces the stress on the arterial vessel at the subclavian site, and enables a stiff balloon or stent catheter to be advanced even through a tortuous and calcified aorta without the risk of dislodging the stent. In the absence of a long sheath, a coronary guide catheter (Judkins right [JR] or MP 6-Fr guide) can be used with a 90-cm-long sheath (Figures 23.9 to 23.11). In very selected cases of kissing stenting when alternative standard approaches fail, the brachial/radial approach can be used: a 6-Fr Terumo radial sheath is inserted into both brachial/radial arteries, and a standard 4- or 5-Fr JR diagnostic catheter is inserted over a 260-cm 0.038–inch Terumo stiff wire through both sheaths. Appropriate alternative long exchange wires can be used. The catheters from both sides are navigated up to the aortic bifurcation, and after selecting the common iliac artery ostia, the wires are navigated through the lesions and advanced into the ipsilateral superficial femoral arteries. The catheters can then be advanced over the wires beyond the occlusions, and the Terumo wires replaced by two 0.038-inch 260-cm Supracor wires. Alternatively, long exchange stiff wires can also be used. In order to facilitate forward movement of the stents without the risk of dislodging them, consideration can be given to the use of two 6-Fr 90-cm Shuttle Flexor introducer long sheaths. These can be advanced over the stiff wires until they reach the common iliac artery ostia. A roadmap technique can be used to check the ostia position in order to properly deploy the selected stent (Figures 23.12 to 23.14).

Zigzag wire technique On rare occasions, wire bias will prevent a postdilatation balloon or a sheath from advancing into a previously deployed stent. A technique that can easily be used to overcome wire bias is the “zigzag” wire technique. Bends are intentionally placed on the wire so that while the balloon or sheath is being advanced, the leading edge of the device being advanced can be lifted off the stent struts and easily advanced into the stent (Figure 23.15).

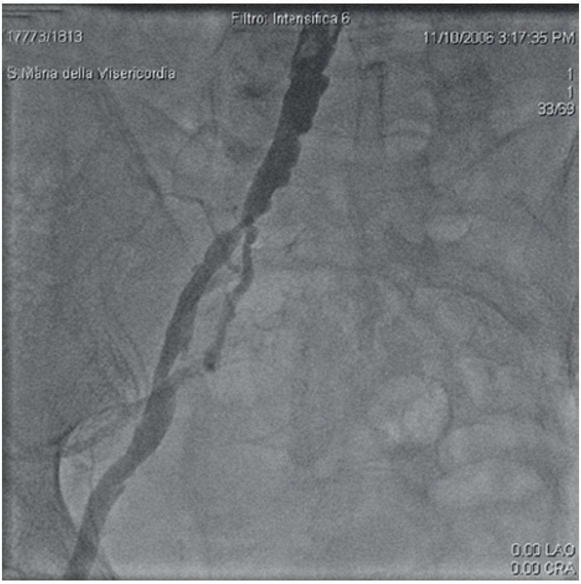

Figure 23.12 Iliac angiography through a diagnostic catheter advanced from the brachial artery.

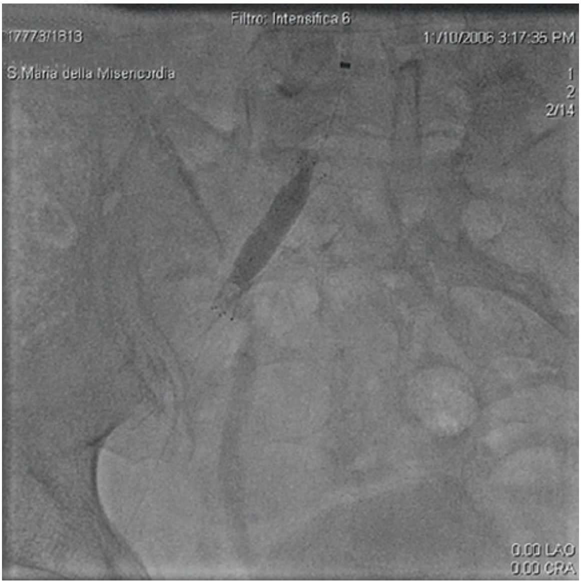
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Figure 23.13 After changing the catheter with a long 6-Fr 90-cm sheath, a soft-tip 260-cm wire is advanced through the lesion, and the stent is correctly deployed using a roadmap technique.

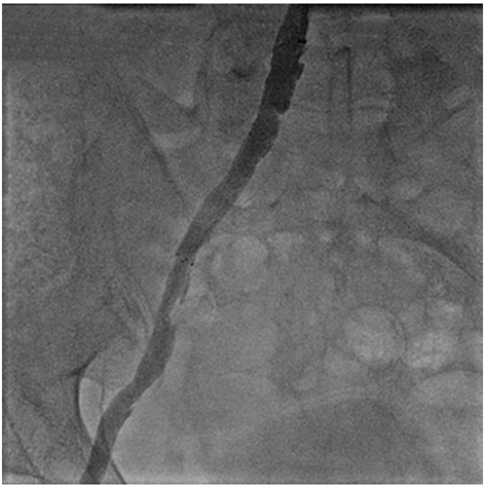

Figure 23.14 Final result after direct injection through the 6-Fr 90-cm sheath.

CHRONIC TOTAL OCCLUSIONS

Due to increased restenosis and reocclusion rates, chronic total occlusions (CTO) of the iliac arteries are usually best treated surgically. However, in patients who are poor surgical candidates or for those who refuse surgery, percutaneous revascularization can still be considered.

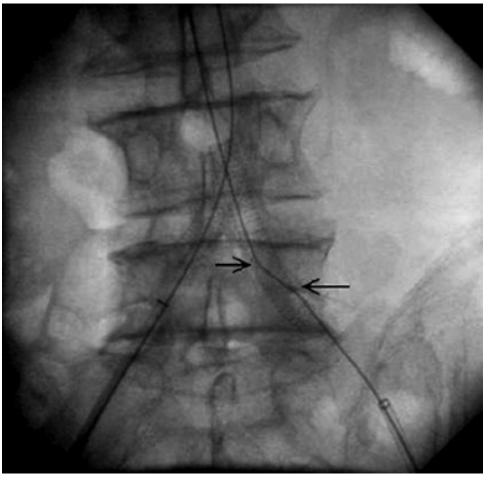

Figure 23.15 Zigzag wire technique in a patient after kissing iliac stents wherein post-dilatation of the left iliac stent was hampered by inability to pass the balloon and sheath through the more distal portion of the stent strut because of wire bias. Arrows show the angles intentionally formed and positioned within the stent to lift off the leading edge of the balloon from the stent struts.

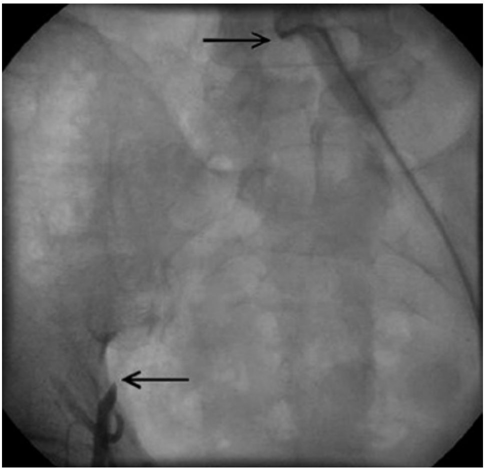

Figure 23.16 Diagnostic iliac angiography fully delineating the proximal and distal extent (arrows) of a CTO using a left internal mammary artery catheter via a left contralateral femoral approach and a sheath injection from the right femoral artery.

Diagnostic Angiography

Adequate lesion assessment is key in planning a strategy for treatment. The full extent of the occlusion should be documented in the diagnostic study. Often, CTA or MRA is extremely helpful in approaching CTOs. In the absence of a noninvasive study, the diagnostic angiogram might need to include more than one vascular access route in order to document the proximal and distal ends (length) of the CTO (Figure 23.16).

The Challenge

The main obstacle in successful percutaneous treatment of an iliac CTO is the thick fibrotic cap on either side of the occlusion. Using a hydrophilic 0.035-inch wire such as the Terumo Glidewire will often allow passage into one end of the fibrous cap since it often has a nipple. If the entire length of the CTO is successfully crossed, the rest of the procedure is done using standard angioplasty and stenting techniques. However, crossing the fibrous cap on the opposite end of the CTO is often cumbersome since the nipple is directed in the opposite direction (Benh vienand has a tendency to deflect the wire away from the lumen and into a dissection plane (Figures 23.17 and 23.18).

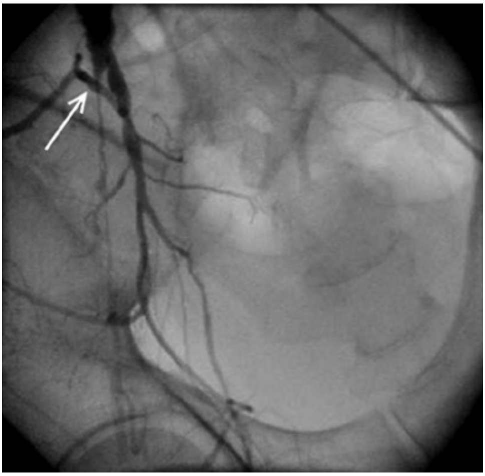

Figure 23.17 Angiogram of the right iliac artery via left contralateral approach revealing total occlusion (arrow) of the external iliac artery with bridging collaterals.

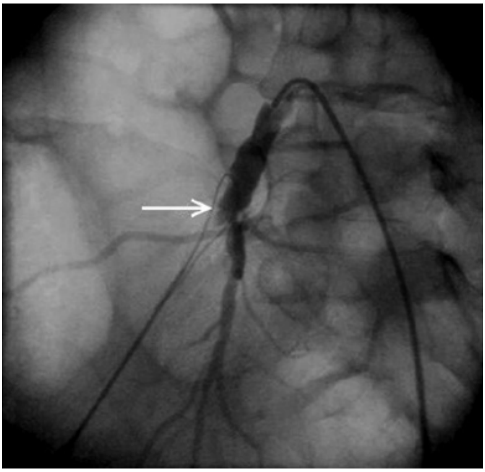

Figure 23.18 The full length of the CTO was traversed through an ipsilateral approach only to encounter resistance in vessel entry at the fibrous cap in the proximal portion of the CTO (arrow). The hydrophilic wire is being directed away from the central lumen and deflected back, essentially doubling up on itself.

Tips and Tricks

****The old "body floss" technique** In these cases, an old but still successful technique consisting of approaching the CTO from two access sites, one from above and another from below, might be the only way to successfully revascularize the iliac artery. Ipsilateral access is established through the femoral artery, and access to the superior portion of the CTO can be through contralateral femoral or brachial/radial access. The choice will depend on the anticipated support that can be gained versus the support that will be needed. In general, brachial/radial access with the use of a 6- or 7-Fr MP guide or long sheath might offer more support as it allows entry of equipment into the iliac artery coaxially with minimal angulation.

A hydrophilic wire, such as a 0.035-inch Terumo Glidewire, is preloaded onto a hydrophilic catheter, such as a Terumo Glidecath. The system is advanced through the ipsilateral femoral artery until it reaches the point of occlusion. The occlusion is probed for a soft spot by pushing the wire against the lesion even if it doubles up. Once a J is formed by pushing the wire against the lesion, the J-shaped portion of the wire will enter the lesion only by having the J-shaped or looped portion enter the CTO. If the J-shaped portion does not advance and only deflects the tip of the wire away from the occlusion, another area of the fibrous cap can be probed until a soft spot is found and the wire loop advanced into the lesion.

Once in the lesion, the Glidecath can usually easily be advanced over the wire into the center of the lesion. Oftentimes when attempts are made to cross the superior end of the occlusion, however, one will end up in a dissection plane in the proximal internal iliac (Figure 23.19) or distal abdominal aorta. This is the rationale for now approaching the superior portion of the occlusion with a similar system, entering the plaque by looping the wire and advancing the loop into the middle of the occlusion, followed by the catheter.

The midportion of the occlusion is almost always softer than the ends because it is usually composed of semiorganized thrombotic material. Within the lesion, the catheters can actually be manipulated and twisted in such a way that they align and are essentially abutting each other. When this occurs, the wire in the catheter inserted through the brachial or contralateral femoral artery can be withdrawn, and the wire of the catheter inserted through the ipsilateral femoral artery can be advanced into the tip of the other catheter

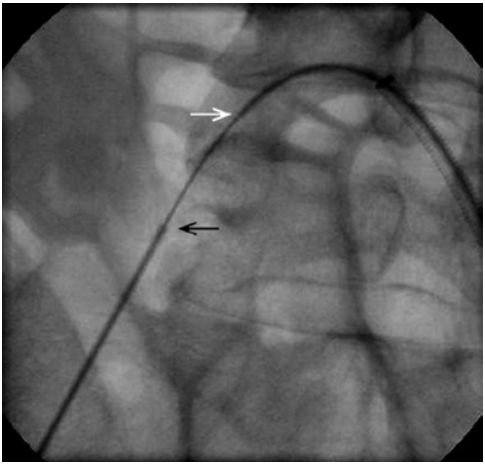

Figure 23.19 "Body floss" technique performed by advancing a hydrophilic wire through one catheter (black arrow), into the CTO, then into a second catheter inserted into the CTO via contralateral approach (white arrow), and eventually externalizing the wire through the contralateral sheath.

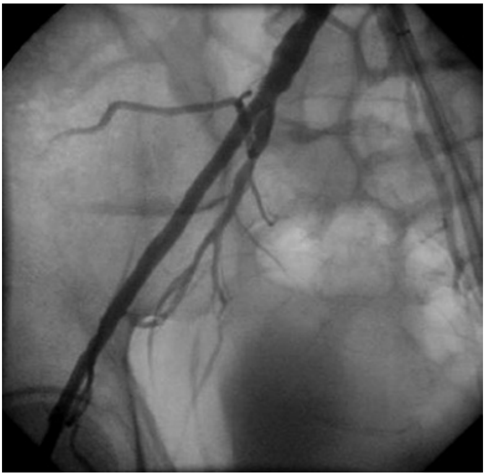

Figure 23.20 Completed procedure from Figure 23.19 after deployment and postdilatation of a long self-expanding nitinol stent.

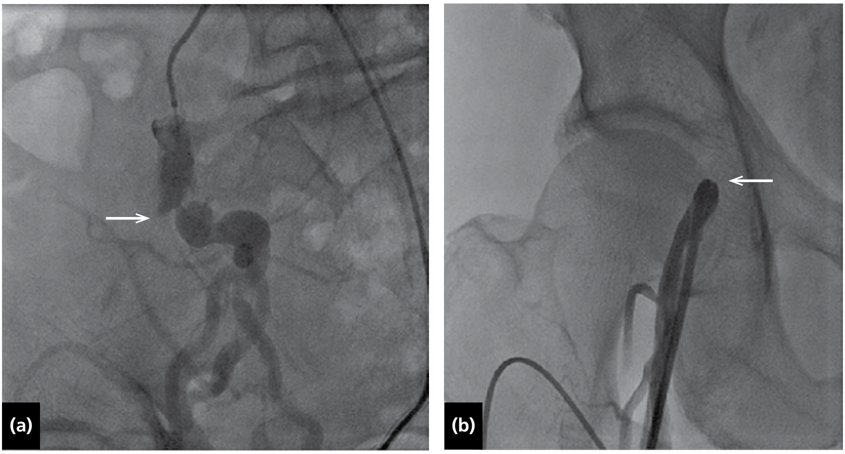

Figure 23.21 (a) Another case of CTO (arrow) with angiography performed via a left contralateral approach. (b) Sheath injection showing the distal extent of the CTO (arrow).

and into the distal aorta, thus establishing a true lumen-to-true lumen tract. The wire can then be externalized, essentially creating "body floss." Once this is achieved, standard angioplasty and stenting techniques can easily be performed (Figures 23.19 to 23.25).

*****Coronary CTO techniques** Even in cases of iliac artery CTO, the preferred recanalization techniques are those used in the coronary CTO field. Coronary CTO wires or dedicated peripheral CTO wires are currently the preferred wires [12]. The manipulation techniques are very similar to the ones used in the coronary CTO field, including antegrade, retrograde, controlled antegrade and retrograde tracking (CART), and reverse CART. Approaches include the

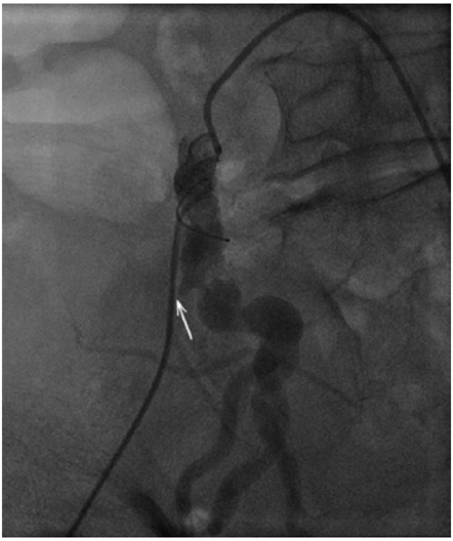

Figure 23.22 Arrow showing entry of the hydrophilic wire and catheter into a dissection plane proximally.

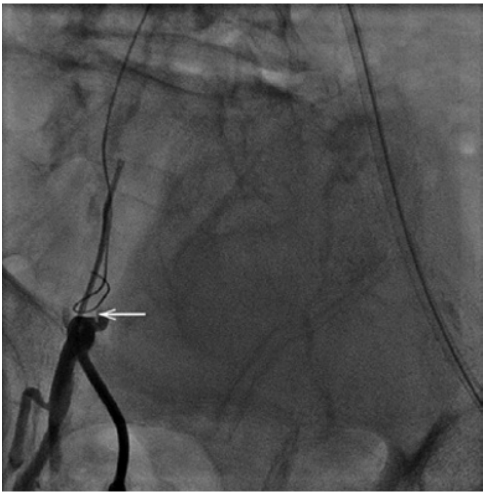

Figure 23.23 Arrow showing inability of the hydrophilic wire to cross the distal extent of the lesion from above. Note the presence of the initial catheter within the CTO from femoral access.

antegrade through the brachial or radial access or the contralateral crossover femoral access and the retrograde through the ipsilateral femoral access; the access is selected depending on the amount of tortuosity and calcium. Through the antegrade approach, a system composed of a long 90-mm (brachial) or 150-mm (radial) 6-Fr sheath, a diagnostic 4-Fr MP catheter, and a coronary CTO wire such as the Fielder XT (A or R) is advanced under fluoroscopy and roadmap technique to the proximal cap in the attempt to cross the occlusion. A coronary 1.5 or 1.25 × 15 or 20 mm balloon or, alternatively, a microcatheter such as a Finecross® or Corsair® can help to manipulate the wire effectively and cross the occlusion. If a through lumen cannot be

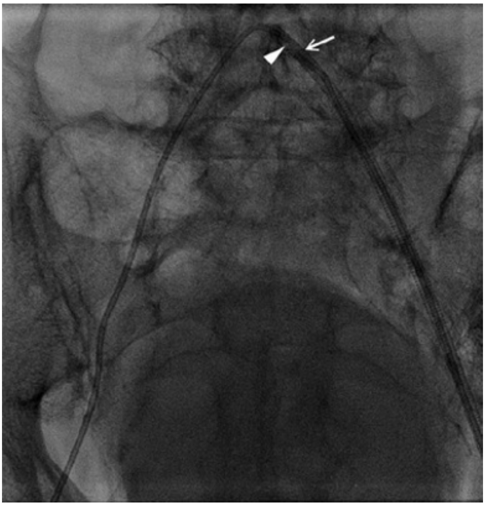

Figure 23.24 Still frame showing successful crossing of the ipsilateral catheter not only into the proximal portion of the left internal iliac artery but into the tip of the crossover sheath (white arrowhead) using the "body floss" technique, where the hydrophilic wire exited the ipsilateral catheter and entered the contralateral catheter within the CTO. The white arrow shows the tip of the contralateral catheter within the crossover sheath.

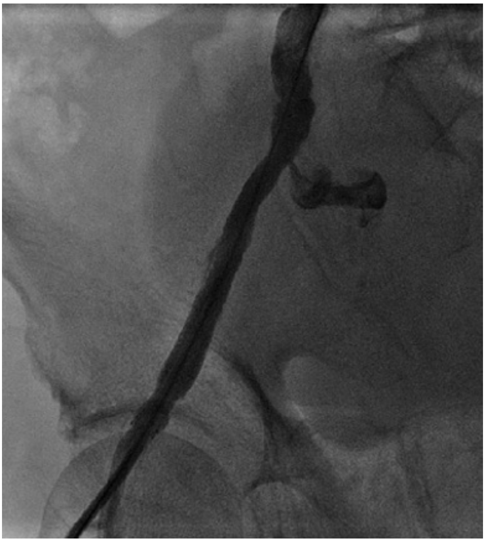

Figure 23.25 Completed procedure after balloon angioplasty and deployment and postdilatation of a self-expanding nitinol stent.

achieved, a Gaia® II or III can usually accomplish the task. After the wire has crossed, the balloon or microcatheter is advanced, the wire is changed for a stiffer 300-mm-long 0.14- or 0.18-inch wire, and the stenting procedure proceeds as usual. Alternatively, a dedicated peripheral CTO wire such as the Astato or the Gaia peripheral can be selected from the start using small peripheral balloons as support.

Through the retrograde approach, the techniques and equipment to be used are substantially the same except for the sheath, which is usually a short 6-Fr standard sheath or a dedicated 40- to 45-cm crossover sheath such as the Destination®. A combination of the two approaches can be selected (CART or reverse CART) if the antegrade or retrograde approach fails, but it is rarely needed.

While working on an iliac CTO, especially a long CTO, it is essential to have a preprocedural CT imaging study with the diameter of the iliac vessels in order to avoid dangerous oversized balloons/stents. Similarly, attention should be paid at every step to patient complaints such as abdominal pain in order to avoid massive rupture/laceration of the vessels, as well as to change the wire, once passed, to a more supportive wire in case a stop-flow balloon or covered stent needs to be inserted quickly.

*****Using the stiff end of the wire** On rare occasions, and only under strict fluoroscopic guidance and confirmation in multiple orthogonal views, the stiff end of a hydrophilic wire can be used to traverse the final portion of a CTO (see Figure 23.17 for baseline angiography; Figures 23.26 to 23.29). This should be used only as a last resort and only after careful consideration of possible consequences such as arterial perforation and rupture.

COMPLICATIONS

Although rare, complications may occur, some of which are potentially lethal [13, 14]. Complications may include distal embolization, stent migration, iliac artery dissection, perforation, and iliac artery rupture.

Perforations

Covered stent availability in the cardiac catheterization laboratory is a prerequisite for iliac artery stenting as well as large occlusion balloons, which may often keep the patient stable until reaching the operating room. Surveillance of the implanted stent is warranted by Doppler ultrasound and, in particular, by CTA and MRA.

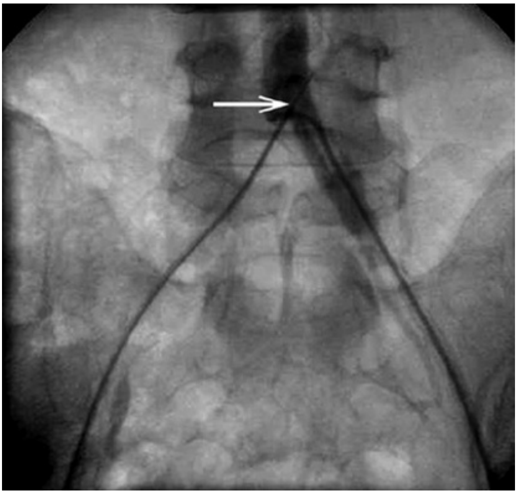

Figure 23.26 The terminal portion of the CTO (arrow) was traversed via retrograde access using the stiff end of the wire.

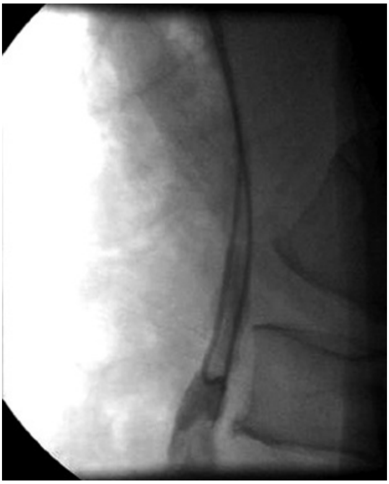

Figure 23.27 The intraluminal position of the wire was confirmed first by injection of contrast through the contralateral catheter.

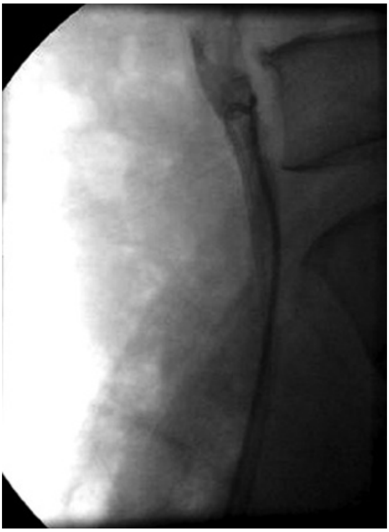

Figure 23.28 After removal of the wire from the ipsilateral catheter, blood is successfully aspirated, the pressure is documented, and intraluminal location is confirmed by injection of contrast in the ipsilateral catheter.

Acute or Subacute Occlusion

Despite its rare occurrence, acute or subacute occlusion of the common or external iliac artery may occur, especially caused by iliac artery dissection during diagnostic femoral procedures or by long-term aortic counterpulsation [9]. In case of acute occlusion, local thrombolytic therapy should be used whenever possible, perfused through a 5- to 6-Fr infusion catheter from the retrograde contralateral or brachial access. In case of

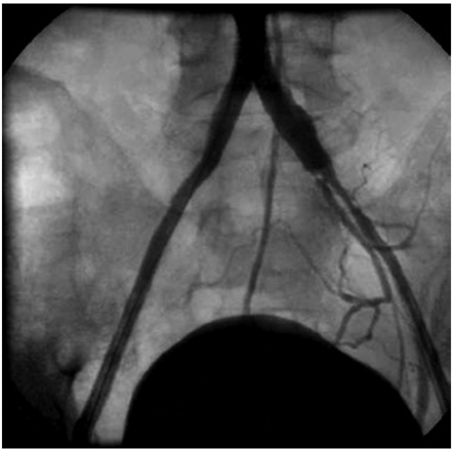

Figure 23.29 Completed procedure after routine balloon angioplasty and deployment of overlapping stents from the common iliac artery down to the external iliac artery.

subacute occlusion, declotting with manual or rheolytic thrombectomy could be successfully performed. Protection with a distal filter should be used whenever possible by placing a large 6- to 8-mm filter from the contralateral approach in the femoral artery. Infusion of antiplatelet agents, such as glycoprotein IIb/IIIa antiplatelet agents, may be helpful and is suggested if there is significant residual thrombotic burden after mechanical thrombectomy.

Iliac Artery Rupture

When faced with an iliac artery rupture or perforation, we recommend immediate balloon tamponade, aggressive reversal of anticoagulants, including the use of protamine to reverse heparin, and transfusions of fresh frozen plasma or platelets as appropriate. Balloon tamponade of the injured vessel may be undertaken with prolonged balloon inflations for up to 15–20 min. However, this may be unsuccessful, and a covered stent should be made available to treat the injured vessel. In the event of significant blood loss, blood transfusions should be given. As a last resort, surgical repair may be required, but this may be associated with significant risk.

Tips and Tricks

****Damage control** Use the brachial access to place an infusion catheter whenever possible to minimize the risk of bleeding. In cases of subacute thrombosis, first perform a manual aspiration thrombectomy with a 6-Fr large-lumen guide and then use any thrombectomy catheter available: this strategy may help to obtain maximal declotting (Figure 25.30). When using a rheolytic catheter (usually a 6-Fr peripheral device), be sure not to aspirate more than 200–250 mL each time because hemolysis can occur.

Case selection Poor infrainguinal runoff is the main risk factor for decreased primary patency stenting to treat TASC (TransAtlantic Inter-Society Consensus) type B and type C iliac lesions. Poor runoff, external iliac artery disease, and female gender are independent predictors of poor outcome after iliac stenting, and therefore the risk for postprocedural embolization and poor flow should be assessed to determine the need for surgical reconstruction: careful patient selection is recommended.

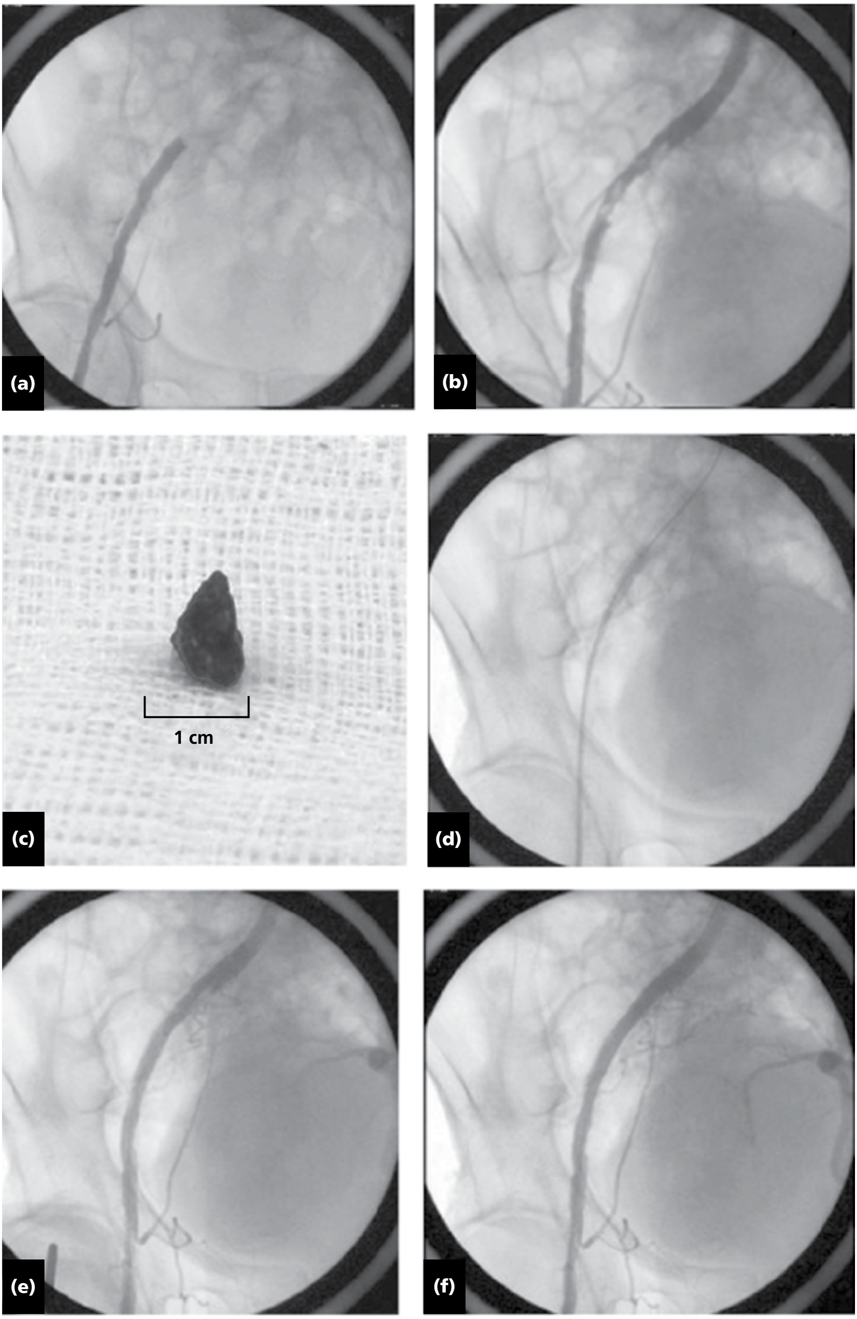

Figure 23.30 (a) Subacute occlusion of the right common iliac artery after prolonged counterpulsation in patients undergoing coronary surgery. (b) Result of 12-h infusion of tirofiban. (c) Manual aspiration and (d) balloon inflation. (e) The residual dissection has been covered with (f) a balloon-expandable stent.

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CHAPTER 24

Renal Artery Denervation

Aravinda Nanjundappa, M. Ayoub Mirza, Kirit Patel, Thach N. Nguyen, and Gianluca Rigatelli

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💧, low risk of complications; 💧💧, high risk of complications

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CHALLENGES

Resistant hypertension (HTN) is defined as blood pressure that remains above the target goal despite concurrent use of three or more antihypertensive medications from different classes, including a diuretic, at maximally tolerated doses [1].

Renal sympathetic hyperactivity is seminal in the maintenance and progression of HTN. Sympathetic nervous activation via efferent nerve fibers lying in the adventitia of the renal arteries leads to increased Na^+ reabsorption, increased renin secretion, and reduction of renal plasma flow. Through afferent sympathetic fibers in the dorsal root of the spinal cord, the kidneys induce a further augmentation of central sympathetic nervous activity [2]. Percutaneous renal denervation of adrenergic nerves in the renal artery was conceptualized to treat resistant HTN [3]. The diagnostic workup includes:

1. **Confirming diagnosis**. Ensure true resistance through ambulatory BP monitoring.
2. **Secondary causes**. Evaluate for hyperaldosteronism, renal artery stenosis, and pheochromocytoma.
3. **Medication adherence**. Assess compliance and optimize therapy.
4. **Target organ damage**. Evaluate for left ventricular hypertrophy, retinopathy, and nephropathy.

BASELINE LABORATORY EVALUATION

Baseline laboratory evaluations – including serum creatinine, glomerular filtration rate (GFR), assessment for anemia, and risk of contrast-induced nephropathy – are essential. In patients with existing nephropathy, appropriate pretreatment is required. If GFR is below 45 mL/min/1.73 m^2, the use of a carbon dioxide (CO_2) angiogram should be considered to reduce the risk of contrast-induced nephropathy. For patients with GFR below 60 mL/min/1.73 m^2, it may be necessary to withhold diuretics, angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARBs), and metformin. If tolerated, intravenous rehydration with isotonic saline should be administered for at least 4–6 hours prior to contrast exposure. All patients should be preloaded with four chewable aspirin tablets.

NONINVASIVE EVALUATION

Computed Tomography and Magnetic Resonance Angiography or Duplex Ultrasound

Review of baseline images of computed tomography (CT), magnetic resonance angiography (MRA), or ultrasound of the renal artery to check for accessory renal artery, diameter of renal artery, presence of renal artery stenosis, and fibromuscular dysplasia (FMD). CT/MRA can help in planning by evaluating the angulation tortuosity and upward versus downward takeoff of the renal artery.

PREOPERATIVE PREPARATIONS

The patient is placed supine in usual cardiac catheterization labs and sterile prep of the bilateral femoral artery. Moderate sedation with versed and Demerol should be achieved at least 10 minutes before the ablation as the procedure can result in significant abdominal, lower back, or pelvic pain. Adequate sedation is needed to minimize associated pain and patient movement that could lead to loss of contact between electrodes and the arterial wall. After positioning the guide catheter, intra-arterial nitroglycerin (200–400 μg) should be administered to prevent vasospasm. Heparin bolus (70–100 U/kg) is given for anticoagulation, and activated clotting time (ACT) is kept between 250 and 300 during the procedure.

ACCESS

Right or left femoral artery access can be used. Vascular duplex ultrasound should be used to image the right common femoral artery (CFA) and micropuncture to access the anterior wall of the CFA free of calcium and plaque. Obtain baseline femoral artery imaging to ensure safe vascular access at a compressible site such as mid-CFA. A short 5-Fr 11-cm sheath is placed, and a pigtail catheter 4- or 5-Fr can be inserted over a 0.035–inch wire. The pigtail is placed at the level of L1/L2 vertebrae.

INVASIVE EVALUATION

Abdominal Aortogram

After confirming hemodynamic stability and an adequate arterial waveform, a digital subtraction angiogram (DSA) of the bilateral renal arteries is performed to visualize the infrarenal aorta, bilateral renal arteries, and renal parenchyma. A breath-hold is essential during abdominal aortography to minimize motion artifacts. A small field of view (FOV) should be selected to maximize the exposure area.

The angiogram should be carefully assessed for the origin of the renal arteries, the presence of renal artery stenosis greater than 50%, arterial tortuosity, accessory renal arteries, and atheromatous plaque at the aorto-renal junction. Additional findings to evaluate include FMD, renal artery aneurysm, dissection, and aortic aneurysm.

A selective renal angiogram is typically obtained in the left anterior oblique (LAO) 15° projection using either an internal mammary (IM) or Judkins Right (JR) 4 diagnostic catheter (5-Fr). This angulation generally provides adequate visualization of the renal arteries.

Quantitative vessel analysis can be used to measure the diameter of the renal arteries. Intravascular ultrasound (IVUS) may also be helpful for precise measurements and for evaluating suspected FMD. Patients with severe renal artery stenosis, FMD, and renal artery aneurysm are excluded from renal artery denervation (RDN).

GUIDES

A 55-cm guiding catheter is advanced over 0.035-inch wire and renal artery selectively engaged. The length of the guide catheter must be shorter than coronary guide given the shaft length of current-generation RDN catheters. The guide catheter's shape depends on the renal artery's takeoff and tortuosity. If downward takeoff is noted, IM is preferred, and horizontal takeoff can be engaged. Other shaped catheters (JR, hockey stick, RDN-1, multipurpose) may be needed based on the anatomical takeoff of the renal arteries. RDN-1 shapes work best for left renal artery down-sloping takeoffs by providing better backup against the contralateral aortic wall. In cases of severely calcified aorta, the no-touch technique is needed in order to avoid dissection of the aorta or the renal trunk (Table 24.1).

Table 24.1 Selection and manipulations of guides

1. Horizontal takeoff	Renal double curve guide catheter or a Judkins Right
2. Superior takeoff	Multipurpose catheter
3. Aortic atherosclerosis	"No-touch" technique.

Tips and Tricks

****No-touch technique** In patients with significant atherosclerotic disease of aorta, a "no-touch" technique should be used. A 0.035-inch wire is maintained in the distal abdominal aorta while positioning the guide close to the renal artery ostium. A 0.014-inch Guidewire is advanced in the renal artery before withdrawing the 0.035-inch wire. This avoids distal embolization and can prevent renal artery dissection.

****Advancement of guide if the position of the device is unstable** Positioning the tip 3–4 mm into the renal artery facilitates delivery of the renal denervation catheter as advancement to (and exit of the renal denervation catheter from) the guide catheter tip typically straightens the catheter slightly and may lead to disengagement. If engagement of the guide catheter proves challenging, consideration may be given to advance a glide wire carefully into the renal artery followed by a 4- or 5-Fr diagnostic catheter as a rail for the guide catheter which, in turn, is gently advanced over the diagnostic catheter in a telescoping fashion.

****Adverse anatomy** Iliac and/or abdominal aortic tortuosity may cause enough friction in the guide catheter that advancement of the renal denervation catheter into the renal artery may not be possible. In this case, a long (e.g. 45 cm) sheath may be used to straighten the iliac/aortic vasculature and mitigate friction. If the renal artery has an acute angle inferior takeoff, guide catheter engagement and support may be suboptimal causing the guide to back out upon renal denervation catheter advancement. In this case, insertion of a 0.014- or 0.018-inch buddy wire into the distal or segmental renal artery may be helpful to offer more support and a stable guide catheter position. It is important to remember to remove the buddy wire during ablation. A sidewinder or Simmons catheter may be helpful in engaging an acute angle inferior renal artery takeoff via the femoral approach, followed by guide catheter advancement using the engaged diagnostic catheter as a rail.

WIRES

Wire selection is a quite important step: A non-hydrophilic 0.014-inch wire with high rail support like a Grand Slam (Asahi Intecc, Nagoya, Japan) or Mailman (Boston Scientific, Marlborough, MA, USA) is advanced into the renal artery. Wire choice depends on the tortuosity of the renal artery branches. For severely tortuous vessels, a wire with soft tip and supportive body like Spartacore (Abbott, Chicago, IL) may be used. Hydrophilic wires should be avoided to prevent distal wire-induced perforation. Attempt should be made to keep tip of the wire away from renal parenchyma to prevent perforation and subcapsular hematoma (which are difficult to damage control).

BEST PLAYERS

There are currently two systems that are approved by Food and Drug Administration (FDA) for RDN for the treatment of resistant HTN: Paradise Ultrasound-based device (Radiance™; ReCor, Palo Alto, CA, USA) and Symplicity Spyral – a radio-frequency (RF) multielectrode renal denervation system (Medtronic, Minneapolis, MN). Both systems allow ablation of renal arteries, branches, and accessory arteries between 3 and 8 mm in size.

GAME PLAN RENAL DENERVATION PROTOCOL

Recor Paradise System

Arterial access

A 7-Fr sheath is placed in the femoral artery (preferably 23-cm Brite Tip sheath (Cordis, Santa Clara, CA, USA) to avoid tortuosity of aorto-iliac artery over a 0.035-inch wire under fluoroscopy). Intravenous heparin is given at 60–70 units per kg, and keep ACT at 200 to 250.

Cannulate the renal artery

Engage the left or right renal artery using a short 55-cm guide catheter with a no-touch technique using 0.035 inch and 0.014 inch non-jacketed wires such as Terumo Run-through or Asahi Sion Blue. Once the guide catheter is close to the ostium of the renal artery, the 0.035-inch wire can be removed. The tip of the wire should be in the distal branch; however, it should be at least 5 mm away from the distal renal parenchyma to avoid inadvertent renal perforations.

Intravascular ultrasound

A simple coronary or peripheral 0.014-inch Volcano ultrasound can be used to measure the size of the renal artery. Care should be taken to watch the introduction of the IVUS catheter on fluoroscopy and not to rely on the premade markers on the catheter due to the short distance of the renal artery from the femoral artery, as well as to avoid renal parenchyma damage.

Preparing the balloon

The RECOR balloon is prepped outside the body and inserted into the renal artery. Sites for ultrasound energy to perform renal denervation are chosen: free of branch vessels and proximal to renal parenchyma. The vessel diameter has to be 3–8 mm.

Conscious sedation and pain management

Prior to starting ablation, 0.5 mg of Versed and 12.5 mg of Demerol are usually administered for pain relief.

Position the balloon

Once the RECOR balloon has expanded into the renal artery, 4 to 6 mL of contrast is gently injected under fluoroscopy to document cessation of contrast proximal to the balloon. This complete apposition of the balloon against the renal artery provides adequate ablation energy.

Ablation

Once the catheter is appropriately positioned, the balloon is automatically inflated at low pressure. Ultrasound energy is then delivered over a 7-second interval, typically with two to three applications per renal artery. A minimum of three ablations is performed on each side, as prior studies have demonstrated that three ablations per renal artery yield a 92% success rate. A hydrocooling system continuously circulates sterile water to prevent excessive heating of the vessel wall during delivery. Upon completion of therapy, the balloon is automatically deflated and should be repositioned proximally for subsequent ablations. For treatment of an accessory renal artery, a different balloon size may be required, as the catheter is connected to an ultrasound generator that adjusts energy output based on the balloon dimensions.

(*Continued*)

Post-ablation management

After the ablation, 200 μg of nitroglycerin is given prior to imaging to prevent spasms. Evaluate the whole parenchyma to ensure no visible perforation, arterial spasm persisting, arterial vessel dissection or occlusion, and distal embolization. A final angiogram is performed, and the procedure is repeated on the contralateral renal artery. The patient is continuously monitored for vital signs of pain and respiratory status. The access site is managed with manual compression versus closure device based on physician expertise and patient anatomy.

Medtronic Spyral Catheter

Simplicity Spyral is a RF-based device designed to perform ablation of renal artery and its branches that are >3 mm in size [4]. Spyral catheter has four radiopaque electrodes at the distal end of 5 mm apart. The electrodes emit RF waves and measure impedance energy and arterial wall temperature. The operator could review the impedance and temperature of each of the four electrodes from a screen on the console and determine whether there is adequate vessel wall apposition for ablation. The electrodes shut off automatically if the contact with vessel wall is lost or there is excessive temperature rise at the point of contact of electrode. Its helical design allows for near-complete circumferential ablation with minimal manipulation of the catheter.

Access

Access is obtained in a similar manner as previously described, and a 6-Fr, 23-cm sheath is introduced via the femoral artery. Following cannulation of the individual renal artery, confirm that the vessel diameter is greater than 3 mm and less than 8 mm. Exclude the presence of vasospasm, renal artery stenosis greater than 50%, FMD, dissection, aneurysm, or complete occlusion.

Wiring

Wire the renal artery with balanced heavy-weight or semi-stiff wire for support and avoid jacketed wire. After advancing the catheter over an 0.014-inch guidewire to the desired location, the guidewire is pulled back allowing the Spyral catheter to take its helical shape so that four electrodes touch the vessel wall (Figure 24.1).

Ablation

Once satisfied with the positioning, the electrodes are selected and deselected through a controller device. A starting impedance of at least 220–250 ohm is ideal. If the impedance is too high, this may indicate that the catheter position is in a small side branch and should be retracted into the bigger branch. Avoid treatment within 5 mm next to a stent or a disease segment.

Each treatment run is delivered over a 60-second period. If the electrode deactivates due to loss of contact or overheating, it may be repositioned and the treatment should be restarted. Treatments lasting more than 45 seconds are considered successful. If the electrode deactivates before 45 seconds of RF energy delivery, the catheter should be gently rotated to improve vessel wall contact, and treatment should be reinitiated at that site.

Upon completion of treatment at a given vessel segment, the catheter is withdrawn and RF ablation is repeated. Treatment typically proceeds from distal to proximal along the branches of the renal artery. The main renal artery is treated last, with care taken to avoid RF delivery at the ostium and within the 5 mm segment distal to it. Area within 5 mm to a bifurcation is also avoided. After treatment completion, the guidewire and RF catheter are removed, nitroglycerin is administered into the renal artery, and a final angiogram is performed. The guide catheter is then advanced into accessory renal arteries or contralateral renal artery measuring >3 mm in diameter, and the procedure is repeated (Figure 24.2).

Pain management

If the patient moves due to pain, the electrode may not be able to deliver the RF energy; hence, pain management is important. After completion of one renal artery, the ablation catheter is withdrawn, and nitro is given to treat potential spasms. Post-ablation imaging ensures no complications such as perforation, spam dissection, or vessel occlusion. Vascular access is managed with a manual compression or closure device.

Discharge and follow-up

Patients can be discharged in 6 hours unless vascular complications are noted. Follow-up is scheduled 4–6 weeks to assess HTN and adjust medications if needed. Patients are sent home on Aspirin (ASA) 81 mg once a day for 4 weeks.

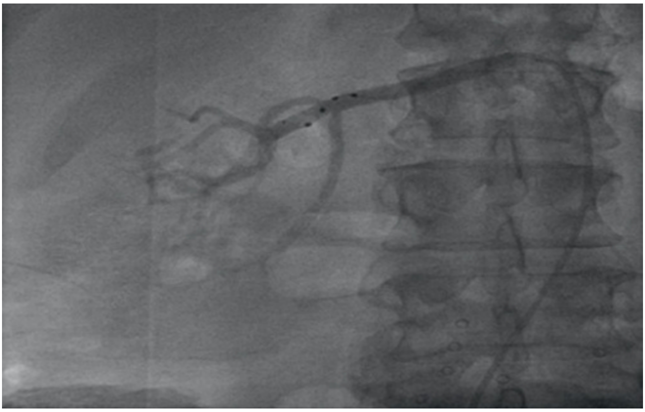

Figure 24.1 Simplicity Spyral catheter in right renal artery.

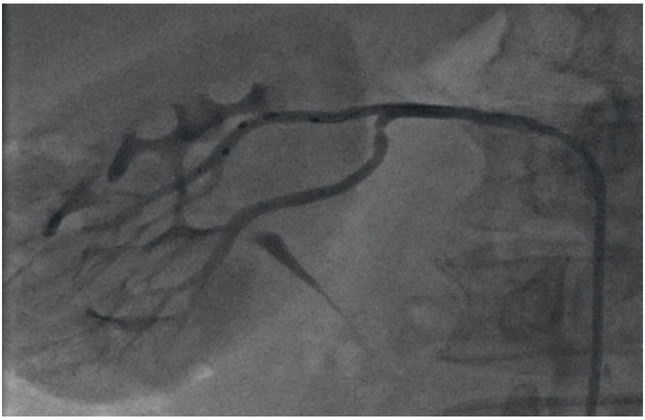

Figure 24.2 Simplicity Spyral catheter at accessory right renal artery.

Tips and Tricks

*****DENERVATION in a patient with renal stenosis or renal stent** When a renal artery stenosis is encountered in a patient with resistant HTN, the renal artery stenosis may be treated with balloon angioplasty and renal denervation performed at a later time if the blood pressure does not reach goal. It is important to avoid ablation in a stented segment as this may cause significant heat-related tissue injury.

COMPLICATIONS

RF ablation is considered a safe procedure when performed by experienced operators, with a complication rate of less than 1%. Vascular access-related complications – such as hematoma, pseudoaneurysm, arteriovenous malformation, arteriovenous fistula, retroperitoneal hemorrhage, HTN, pain at the access site, and occlusion of the CFA leading to limb ischemia – are theoretically possible but have not been reported in clinical trials involving over 6000 patients. Similarly, renal-specific complications, including renal artery dissection, vessel occlusion, parenchymal perforation, atheroembolism, and renal infarction, have been described as potential risks but were not observed in these trials. Patients typically undergo short-term observation post-procedure and are discharged the same day.

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CHAPTER 25

Pulmonary Embolism

Marco Zuin, Huu Than Huynh, Ngan T. Truong, and Barun Agarwalla

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CHALLENGES

Pulmonary embolism (PE) is the third leading cause of cardiovascular mortality worldwide after myocardial infarction and stroke [1, 2]. Life-threatening acute PE results from (1) acute direct mechanical obstruction of the pulmonary arteries, (2) right ventricular overload resulting in acute right ventricular failure, and (3) reduced cardiac output leading to hemodynamic shock. Rapid endovascular treatment with prompt central clot debulking relieves life-threatening ventricular strain and restores adequate pulmonary perfusion.
The initial management of PE focuses on ensuring acute survival through hospital discharge. Moreover, the choice of management impacts long-term survival as well as the development of chronic thromboembolic pulmonary hypertension.

GAME PLAN

Once PE is suspected, the patient should have an urgent electrocardiogram, transthoracic echocardiography, and laboratory investigation, including troponins and B-type natriuretic peptide (BNP) or pro-BNP. Based on these findings, the PE can be classified as massive, submassive, or low risk, according to the current American Heart Association stratification. This risk stratification assists in an evidence-based selection of conservative, pharmaco-invasive, catheter-based, or surgical management.

HIGH-RISK MARKERS AND RISK STRATIFICATION

Patients with signs of hemodynamic instability (Table 25.1) should emergently receive reperfusion, being a life-threatening condition [3–5]. However, risk stratification of these patients should also include the assessment of the probability of major bleeding events, including intracranial hemorrhage [6–8]. Absolute contraindications for systemic thrombolysis are listed in Table 25.2.

Table 25.1 **Findings suggestive of high-risk pulmonary embolism**

Patient presentation	Electrocardiographic changes	Laboratory values	Radiographic findings
Sudden-onset presyncope or syncope Hypotension Extreme hypoxemia Electromechanical dissociation Cardiac arrest	New right bundle branch block Anteroseptal ST-segment elevation or depression Anteroseptal T wave inversion Signs of right ventricular strain including S1Q3T3 pattern	BNP >90 pg/mL or pro-BNP >500 pg/mL Elevated troponin I (>0.4 ng/mL) or troponin T (>0.1 ng/mL).	RV dilation based on CT scan or echocardiography (in four-chamber view, RV:LV diameter ratio >0.9)

BNP = B-type natriuretic peptide; LV = left ventricle; RV = right ventricle.

Table 25.2 **Absolute and relative contraindications for full dose of systemic thrombolytic therapy**

Absolute contraindications	Relative contraindications
Previous history of hemorrhagic stroke	Major surgery within the last month
Ischemic stroke within 3 months	Thrombocytopenia
Pregnancy	Uncontrolled severe hypertension
Head trauma or neurosurgery within 6 months	Cardiopulmonary resuscitation
Known intracranial neoplasm	
Suspected aortic dissection	
Internal bleeding within 6 weeks	
Active bleeding or bleeding diathesis	

SYSTEM-BASED PRACTICE

The Pulmonary Embolism Response Team (PERT) Model [9,10]

The treatment of PE was traditionally fragmented among multiple providers; therefore, many community hospitals and academic centers have established dedicated PERTs to achieve higher levels of coordination and expertise. The PERT model allows for multidisciplinary input to inculcate better clinical gestalt and treatment decisions regarding escalation of care in complex patients, especially those with submassive PE. Several catheter-directed techniques (CDTs) are available for PE, such as ultrasound-assisted thrombolysis, rheolytic embolectomy, aspiration/mechanical thrombectomy, and thrombus fragmentation [11–13].

Tips and Tricks

****Two catheters in one vein** In a case of saddle or bilateral PE, a catheter should be placed in each of the two main pulmonary arteries. Therefore, two venous accesses are required. Although these can be obtained in both common femoral veins (CFVs), it might be easier on the patient if dual access is obtained in one CFV only. Use of one CFV allows some mobility of the other lower extremity. Ipsilateral CFV access should not be obtained if there is coexisting iliofemoral deep vein thrombosis (IF-DVT). In the case of bilateral IF-DVT, internal jugular or subclavian vein access should be considered. Always utilize ultrasound-assisted venous access, which allows detection of undiagnosed CFV thrombus and minimizes the probability of an arterial puncture.

In general, the CFV is of oblong shape (Figure 25.1a) and can expand to two or three times its baseline size when the patient performs a Valsalva maneuver (Figure 25.1b). However, if the patient has pulmonary hypertension, the vein does not dilate significantly.

****Right heart catheterization and pulmonary angiogram** Pulmonary artery (PA) pressures should be obtained prior to pulmonary angiography. It is best to access the PA by using a Swan–Ganz or Baim–Turi catheter and acquire hemodynamic data and mixed venous oxygen saturation from the PA. If the patient can cooperate by holding their breath, digital subtraction angiography is preferred as it requires less contrast medium than conventional angiography. Additionally, it allows better detection of PE in peripheral pulmonary vessels (Figure 25.2). Ideally, thrombus should be confirmed in two projections as a filling defect. Amputation of a pulmonary arterial branch is also consistent with PE.

****How to selectively enter a pulmonary artery** The left PA is most often the easiest to cannulate. There can be difficulties accessing the right PA due to angulation from the main PA trunk. If a 5-Fr angled Berenstein catheter or diagnostic JR4 catheter cannot be successfully directed into the right PA, using a 6- or 7-Fr guide may be considered as the next option to

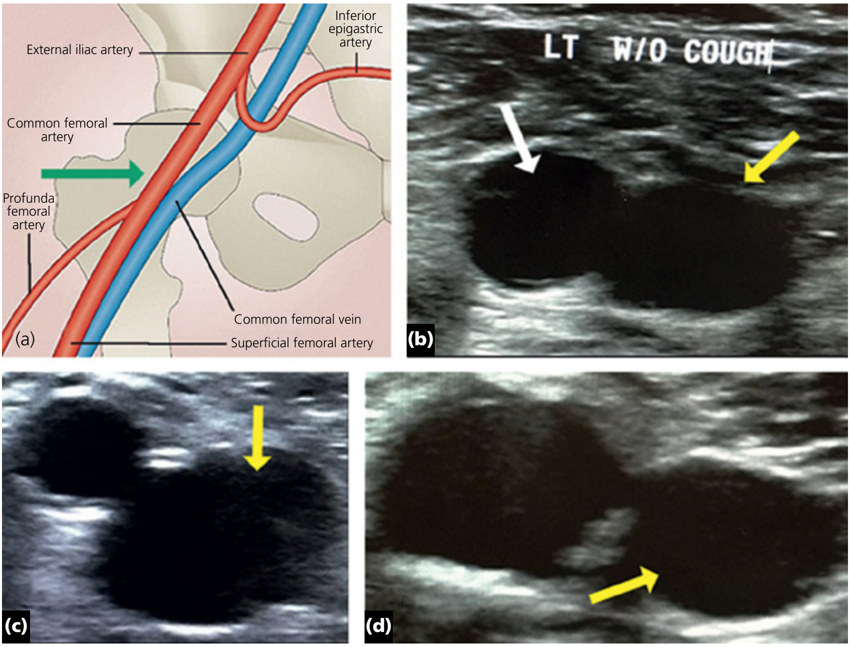
Inferior epigastric artery
External iliac artery
Common femoral artery
Profunda femoral artery
Common femoral vein
Superficial femoral artery
(a)
LT W/O COUGH
(b)
(c)
(d)

Figure 25.1 (a) The common femoral artery and vein were measured at the level immediately proximal to the bifurcation of the superficial and deep (i.e., profunda) femoral artery (green arrow) (b) In this ultrasound image, the common femoral artery was identified as a round structure in the left (white arrow) and the common femoral vein in the right (yellow arrow). Without cough (W/O cough), the diameter of these vessels were of the same approximate size. The vein was easily identified because it collapsed when the probe was pressed down while the artery would stay the same (not shown here). Calcium deposits could be seen on the wall of the common femoral artery. (c) In the patient with shortness of breath, the diameter of the common femoral vein was larger, even twice or three times larger than the diameter of the femoral artery. (d) In contrast, in the patient with bleeding, the diameter of the common femoral vein was smaller than the diameter of the common femoral artery.

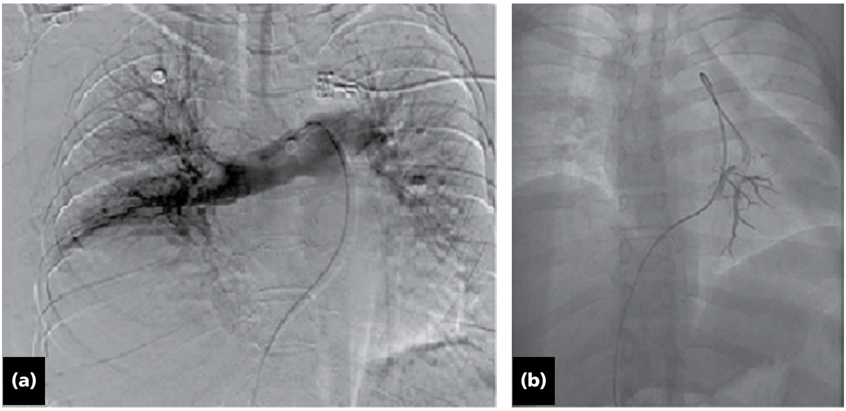

Figure 25.2 Angiography of pulmonary embolism. (a) Non-selective angiography demonstrating bilateral lower lobe pulmonary embolism. (b) Selective left pulmonary artery angiography demonstrating left lower lobe pulmonary embolism.

provide more support, along with the use of a stiff Glidewire (company, city, state). The catheter is positioned in the proximal main PA with the angle facing the intended target, and the wire is gently advanced to probe for the direction of the right PA. If multiple attempts fail to result in successful cannulation of the right main PA branch, a pulmonary angiogram could be performed to assist cannulation.

THROMBUS FRAGMENTATION

If there is a large thrombus burden, such as in saddle PE in a patient with significant hemodynamic compromise, thrombus fragmentation using manual rotation of a pigtail catheter or Amplatz catheter can be performed quickly and result in reduced pulmonary vascular resistance [19, 20]. The disadvantage is distal embolization of clot into segmental pulmonary arteries resulting in hemodynamic compromise, usually when the thrombus is non-obstructive to begin with. It is preferred to utilize some localized thrombolysis following manual disruption of the thrombus, because the chance of clinical success with thrombus fragmentation alone is quite low.

In a retrospective review, thrombus fragmentation alone yielded clinical success in a very small proportion of patients [19]. However, the success rate increased to 71% when thrombus fragmentation was combined with a systemic thrombolytic agent but increased further to 95% when a thrombolytic agent was delivered locally.

WARNING

Pigtail fragmentation is effective at debulking proximal thrombus; however, distal embolization to segmental and subsegmental PA branches has been described with resulting elevation in PA pressure. This situation would require adjunctive aspiration thrombectomy to complete treatment.

Tips and Tricks

****Aspiration thrombectomy** Large-bore sheaths or catheters (8–9 Fr) can be used to perform suction thrombectomy using negative pressure if other devices fail. It is important to know that conventional sheaths with a hemostatic valve will result in thrombus being trapped in the sheath. The trick is to replace the hemostatic valve with a Tuohy–Borst adapter (Cook Medical Inc., Bloomington, IN, USA). Similar results can be achieved with an 8-Fr GuideLiner® catheter (Vascular Solutions, Inc., Minneapolis, MN, USA).

****Catheter-directed thrombolysis** A 0.035-inch wire (e.g. Glidewire) is used to cross the thrombus burden, and its intraluminal position in a segmental PA is confirmed using contrast. Subsequently, the diagnostic catheters can be exchanged for catheters utilized for catheter-directed thrombolysis (e.g. the Uni-Fuse™ catheter (Unifuse; Angiodynamics; Queensbury, NY, USA) or ultrasound-accelerated catheters endovascular system (EkoSonic®) (EKOS Corporation – Boston Scientific, Natick, MA, USA) [Figure 25.3]) using an exchange-length wire. Care is taken to avoid entrapment of the catheter in the tricuspid valve chordae. Caution is suggested with these techniques to avoid perforation of a distal PA or inadvertent catheterization of a small pulmonary branch. A total of 1 mg/h of tissue plasminogen activator (tPA) is infused diluted in normal saline for 12–24 hours.

Once the EKOS® catheter(s) are in place, the ultrasound core is advanced to the end of the catheter. The thrombolytic infusion is started, and the catheters are secured in place. At the end of the thrombolytic infusion, saline can be substituted until such time as the catheters can be removed. Prior to removal of the CDT catheters, repeat PA pressure measurements can be obtained to detect any improvement, which might help guide further treatment strategy.

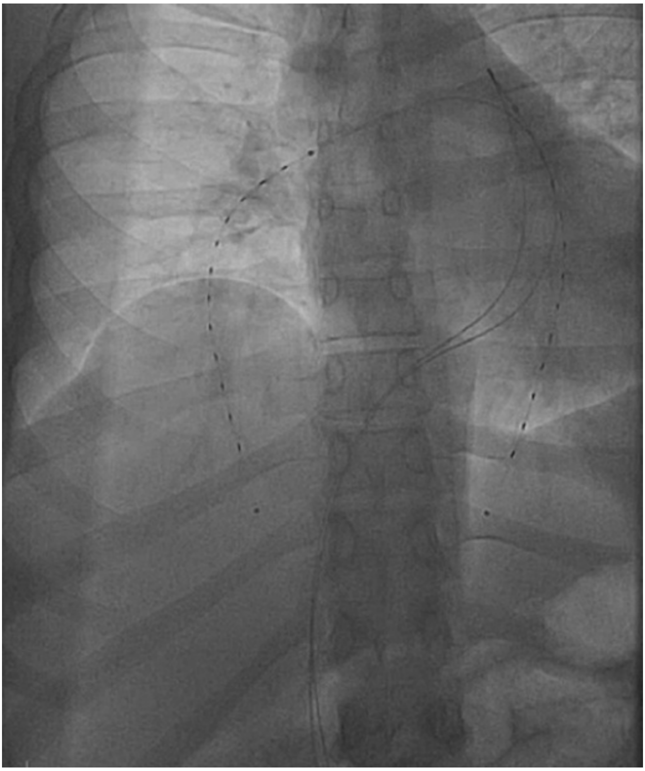

Figure 25.3 Two catheters of the EkoSonic Endovascular System (EKOS). A catheter is placed in each pulmonary artery.

ENGINEERING EXPLANATION

EKOS Ultrasound Energy Technology

This technology relies on the principle of catheter-based lysis with the use of noncavitational ultrasound energy (Figure 25.3). Most plasminogen receptors within a newly formed clot are usually embedded within, and blocked by, fibrin strands. When the EKOS catheter is placed within the clot, it emits ultrasound waves that help to rarefy the fibrin strands; this allows more lytic drug to permeate the clot, leading to higher effectiveness of local dose and, more importantly, limiting systemic dose of the fibrinolytic [14, 15]. The device consists of a catheter with numerous side holes to infuse thrombolytics and a core filament (placed in the catheter's central lumen) with several small ultrasound transducers (frequency of 2.2 MHz).

Advantages of EKOS over other CDTs

Faster and more effective fragmentation of thrombus is the paramount benefit derived from this system. Treatment times can be reduced significantly. The quick set-up allows time-saving in the catheterization laboratory, and a reduction in overall dose of thrombolytic reduces bleeding risk. Additionally, adenosine-mediated sequelae are reduced. There is a potentially decreased risk of distal embolization. Moreover, hemolysis and hyperkalemia associated with rheolytic thrombectomy have not been reported with the ultrasound-mediated CDT.

TROUBLESHOOTING

If flow through the infusion catheter becomes slow, avoid using a high-pressure infusion option to clear the flow. Consider repositioning or replacing the catheter. Potential complications are related to cannulation of the PA and not specific to the ultrasound technology.

BEST PLAYER

aka Standard of Excellence

Routine measurement of post-thrombolysis PA pressures can be performed easily in the ICU setting in order to compare with pre-thrombolytic measurements. A reduction in PA hypertension following thrombolysis is the hallmark of successful thrombolysis, and a consequent decrease in the right ventricle:left ventricle diameter ratio within 48 h is usually expected.

Tips and Tricks

****Location of infusion point** There is little benefit in local thrombolytic administration proximal to target vessel occlusion. If local thrombolysis is performed, it is vital to infuse tPA directly within the clotted vessel (intraclot administration) to achieve optimal results.

WARNING

The AngioJet (Possis, Minneapolis, MN, USA)

Patient symptoms or bradyarrhythmia warrant immediate cessation of use. Wait for at least 1–2 min after normalization of heart rate before resuming.

WARNING

Using Stiff Wires

When planning PA thrombolysis, an exchange-length wire should be used to allow for selective catheterization and subsequent exchange over the thrombolysis catheter. Some operators will use a Glidewire or stiff Glidewire that was initially used to access the occluded PA segment to place a subsequent thrombolysis catheter. However, there is a higher chance of inadvertent wire removal from the selected vessel during the exchange. Therefore, it is advisable to place a 3-mm J wire or a floppy-tipped wire to perform exchanges once the intended vessel has been selected.

FLOWTRIEVER®

FlowTriever Retrieval/Aspiration System (Inari Medical Inc., CA, USA)

The FlowTriever Retrieval/Aspiration System is a catheter-based mechanical thrombectomy device for percutaneous endovascular retrieval of emboli from the peripheral vasculature and is also intended for use in the pulmonary arteries. It was cleared for use by the US Food and Drug Administration (FDA) in 2018. The FlowTriever catheter contains a nitinol

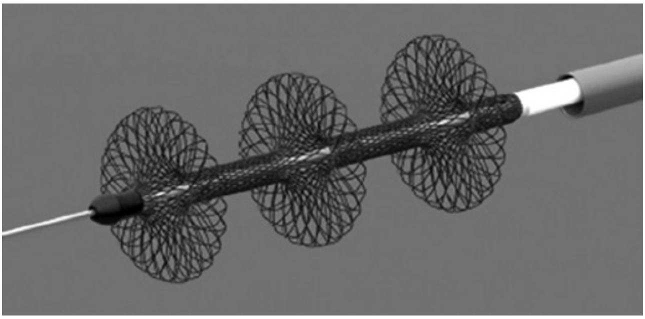

Figure 25.4 FlowTriever catheter with disks deployed advanced through aspiration guide catheter. Source: Reproduced from Inari Medical, Inc.

disk frame that is advanced from the femoral vein and deployed in the pulmonary thromboembolus (Figure 25.4).

Advantages When compared to other thrombectomy devices, the FlowTriever system allows for immediate removal of a large volume of thrombus burden, restores flow, and can bring about a faster improvement in hemodynamics. It defrays the risk of a 12–24-hour infusion of thrombolytic drugs. Its maneuverability allows it to be directed to the exact location of the thrombus.

Limitations The limitations include a larger-bore access (22 Fr). The system requires precise localization of the largest thrombus burden, which necessitates contrast use in the catheterization laboratory that is not mandatory when other devices are utilized.

Procedure Access is obtained in the femoral vein once thrombus at the access site has been excluded. Baseline pulmonary pressures are obtained using a balloon-tipped catheter. An exchange is made for a Grollman catheter, and selective pulmonary angiography is performed in each lung. Once the target thrombus has been identified, a supportive wire (Amplatz Super Stiff™ or Supra Core) (Boston Scientific Corporation, Boston, MA, USA) is directed through the lesion. Sequential dilatation at the venous access site is performed, and a 22-Fr Gore® DrySeal sheath (WL Gore and Associates, Flagstaff, AZ, USA) is inserted. The 20-Fr aspiration guide catheter (AGC) is directed carefully through the tricuspid valve into the PA. Using alternating tension and relaxation of the wire, the tip of the AGC dilator can be directed in such a way as to avoid vascular and cardiac trauma. The AGC is left at the proximal edge of the thrombus. The appropriately sized FlowTriever catheter is advanced through the thrombus and is deployed (Figure 25.4). The retraction/aspiration device is attached, followed by aspiration. The catheter is removed over the wire, and the thrombus can be removed from the device. Depending on the amount of residual thrombus, the device may be reinserted or redirected to another PA for additional thrombectomy (Figures 25.5 and 25.6). Once the catheters are removed, a figure-of-eight suture using 0 silk is used to close the soft tissue track to facilitate hemostasis.

ANGIOVAC THROMBECTOMY

The AngioVac Device

The AngioVac device (AngioDynamics, Latham, NY, USA) consists of a large-bore cannula with a balloon-actuated, expandable, funnel-shaped tip coupled with a circuit and filter [23, 24]. Pump and reinfusion catheter are necessary to provide extracorporeal bypass (Figure 25.7). The

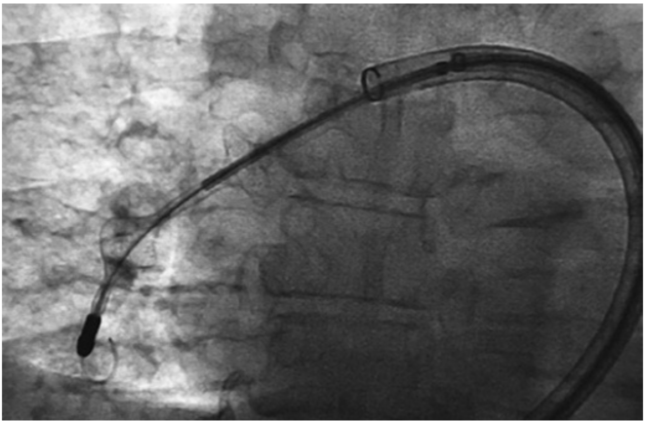

Figure 25.5 FlowTriever system. Disks deployed in right pulmonary artery just before retraction/aspiration.

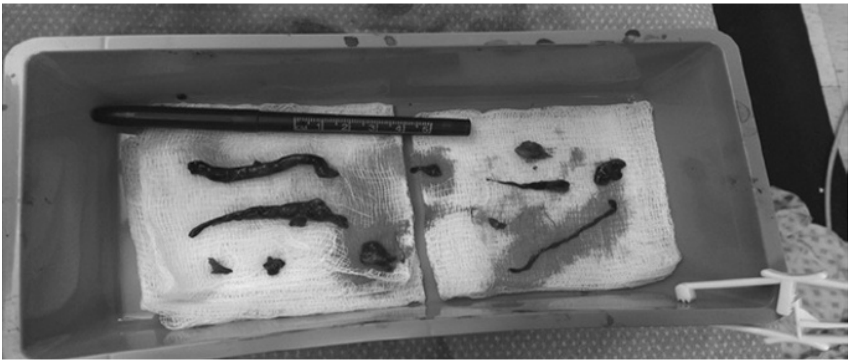

Figure 25.6 Pulmonary thrombi. Example of pulmonary thrombus removal with the FlowTriever procedure.

system facilitates en bloc removal of foreign material – thrombus, tumor, or vegetation – from the vena cava, right heart, and pulmonary trunk (Figure 25.8). It allows suction-assisted removal of intravascular debris while returning blood to the patient and maintaining hemodynamic stability with a veno-venous circuit.

Procedure All procedures are performed using general anesthesia. Femoral venous cannulation is performed either by cutdown or percutaneous access. Surgical cutdown is generally used in cases involving thrombosis of the CFV to facilitate a hybrid procedure with thromboembolectomy of the CFV and lower extremity, with subsequent insertion of the AngioVac cannula for suprainguinal evacuation. In some cases, including selected patients with CFV thrombosis or difficult pelvic anatomy, the internal jugular vein is used for insertion of the inflow cannula and/or the venous return catheter. The initial iteration of the AngioVac was 22 Fr and required a cutdown in all cases. In subsequent cases with the 18-Fr AngioVac, the femoral or internal jugular vein can be accessed percutaneously and serially dilated to accommodate a 22-Fr Gore DrySeal sheath.

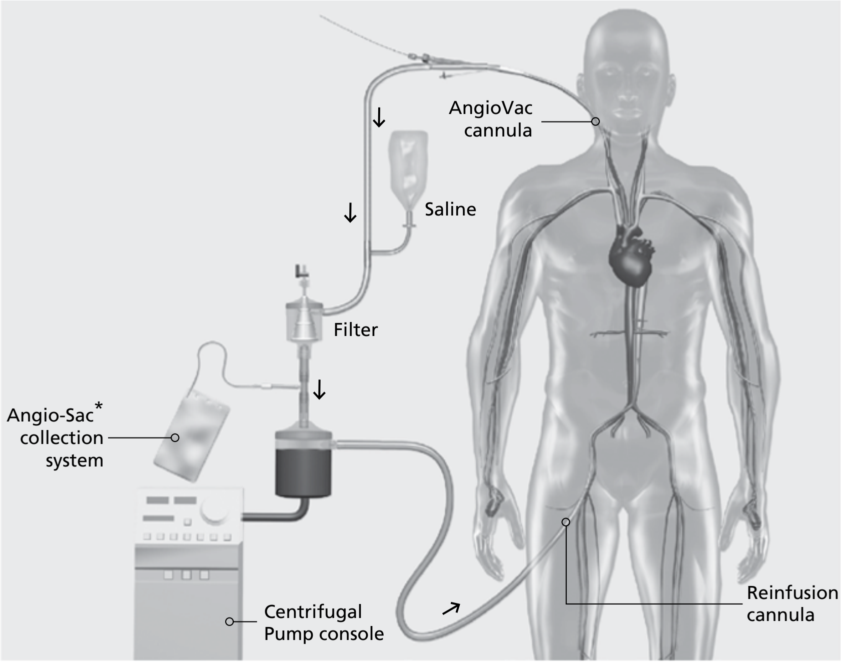

Figure 25.7 The AngioVac device setup. Components necessary for suction thrombectomy, with arrows indicating direction of blood flow. A centrifugal pump drives blood from the AngioVac cannula (22 Fr) through an integrated filter and back to the patient through a de-aired, saline-primed circuit and reinfusion catheter (19 Fr). Source: Reproduced with permission of AngioDynamics, Latham, NY, USA / John Wiley & Sons.

The 18-Fr AngioVac cannula and its dilator are inserted into the sheath over an Amplatz Super Stiff 0.035-inch wire and advanced to the area of interest under direct fluoroscopic and, when appropriate, transesophageal echocardiographic guidance. In some cases, a 0.035-inch Lunderquist® Extra Stiff double curved wire (LES; Cook Inc., USA) might be required to deliver the cannula to the desired location. The dilator and guidewire are then removed, and the AngioVac cannula is temporarily clamped. Additional femoral or internal jugular venous access is obtained, and a 19-Fr or 17-Fr reinfusion catheter is inserted. The AngioVac circuit is then completed with the filter included; priming and thorough de-airing are performed in conjunction with a perfusionist. Anticoagulation should be maintained throughout with intravenous heparin titrated to an activated clotting time of >250 s.

The extracorporeal circuit is then activated and blood circulated in veno-venous fashion: blood is suctioned from the patient via the AngioVac cannula, circulated through a centrifugal pump generating flow rates of up to 4 L/min (2500–4000 rpm), and then returned directly to the patient via the reinfusion catheter. The AngioVac cannula is placed adjacent to the intravascular debris or clot and then repeatedly advanced slightly and withdrawn. Progress can be actively monitored by transesophageal echo; it is not unusual to witness sudden disappearance of large filling defects en bloc. Hemodynamic status is monitored closely by anesthesia. Aspirant is collected in a filter trap and sent for cytological and microbiological analysis (Figure 25.9).

It is useful to measure right heart pressures and cardiac output before and after thrombectomy using a 7-Fr Swan–Ganz catheter. Packed red blood cells should be kept on hand and transfused as needed. At completion of the case, vascular closure can be achieved at both cannulation sites. For femoral approaches, closure is achieved percutaneously using a buttressed

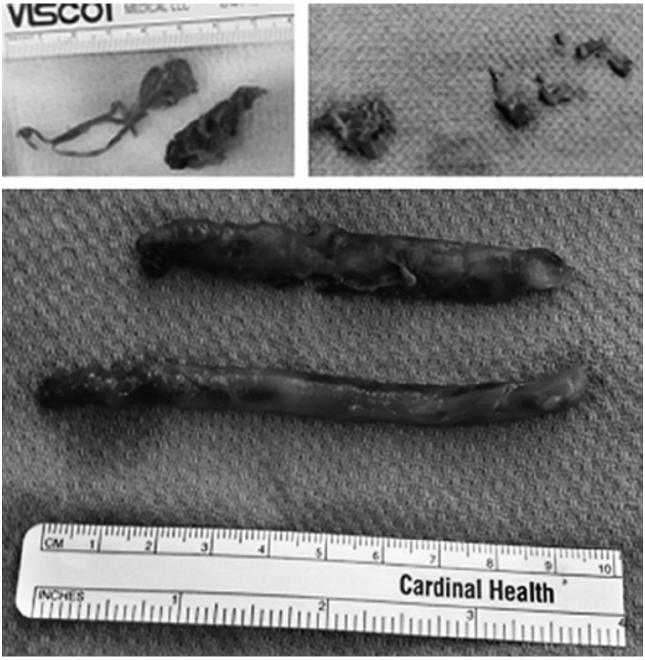

Figure 25.8 Examples of thrombotic material removed by AngioVac. Upper left: a complex mass removed from the right atrium, where it was freely mobile and tethered by a thin band of fibrous tissue to a catheter in the superior vena cava. Upper right: fragments of partially organized thrombus and debris removed from the right main pulmonary artery. Lower panel: massive clot in transit suctioned en bloc from the right atrium, where it extended across the tricuspid valve.

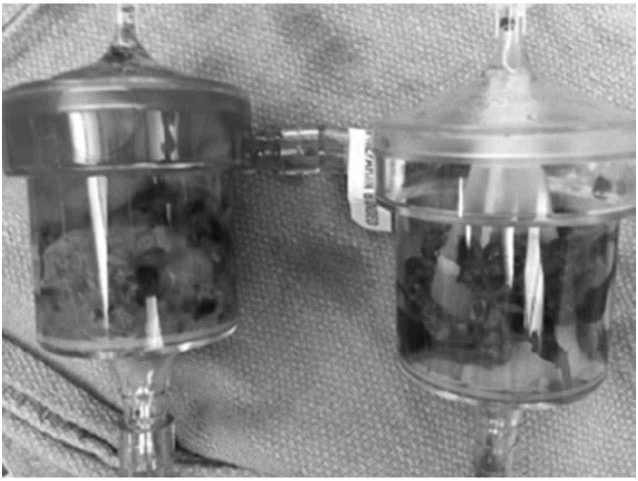

Figure 25.9 Debris isolated by AngioVac thrombectomy. Aspirant from a right atrial mass collected in a filter trap.

horizontal mattress suture that is removed on the second to fourth postoperative day. When access is obtained using a surgical cutdown, the vein itself is controlled with a purse string suture reinforced with a figure-of-eight stitch.

Advantages of AngioVac over CDT/EKOS® Most thrombus in patients with massive PE is located proximally within the large-caliber vessels. Because CDT/EKOS was primarily designed for the peripheral or coronary vasculature, it has some size mismatch issues that may prolong time to treatment or symptom resolution, an issue critical in patients with massive clot burden and critical hemodynamics. The large caliber of the AngioVac system allows instant and near-complete evacuation of the clot. There is no need for adjunctive fibrinolytic therapy and, hence, AngioVac may have a niche for treatment of clotted inferior vena cava filters.

Limitations Large-caliber access and the need for anesthesia and a perfusionist, as well as surgical backup, are the major limitations for use of the AngioVac thrombectomy system. These factors generally limit its use to tertiary care centers.

Planning the procedure An extensive risk/benefit discussion with patient and their next of kin should be part of the shared decision-making process. Following the pattern of a "heart team approach," close collaboration with a cardiac/vascular surgeon is mandatory. Generally, these factors limit the use of this device to nonemergent cases. A hybrid catheterization laboratory lends itself well to carrying out these procedures. Availability of the skill set to manage large-bore access is important to minimize access site complications.

WARNING

Aspiration and Blood Loss Anemia

Be aware that in the pulmonary circulation there is the potential for aspiration of a large volume of blood (between 200 and 500 mL) and blood loss anemia should be a consideration if significant thrombus is to be removed.

TROUBLESHOOTING

What if There Is Thrombus in the Right Heart?

If thrombus is visualized in the right atrium or ventricle on CT or echocardiography, it might be best to avoid CDT in these patients because catheter manipulation through the right heart can result in embolization into the pulmonary circulation. Additionally, patients with a known right-to-left shunt (i.e. patent foramen ovale or atrial septal defect) are also at risk of systemic embolization with consequences as dire as stroke, and therefore are not ideal candidates for CDT unless large-bore thrombectomy devices such as AngioVac are utilized first to aspirate thrombus from the right heart.

Hemodynamic Support

The cause of death in patients with massive PE is primarily cardiovascular collapse from acute right ventricular failure. A secondary complicating factor is hypoxemia from reduced blood oxygenation. For patients with persistent shock or impending cardiac arrest, initiation of extracorporeal membrane oxygenation (ECMO) can sustain perfusion and oxygenation until recovery can occur [21]. ECMO can be used in conjunction with surgical thromboembolectomy for massive PE. For pure right heart failure without the need for extracorporeal oxygenation, insertion of a percutaneous right ventricular assist device (Impella RP®) (Abiomed, Danvers, MA, USA) has been shown in case reports to be helpful in alleviating right heart failure [22] (Figure 25.10).

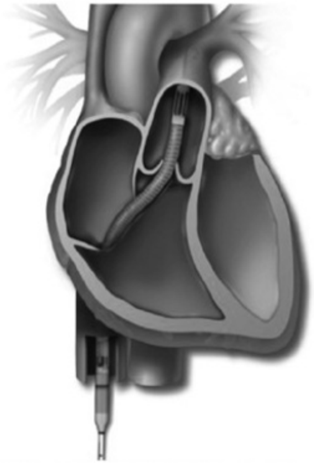

Figure 25.10 The Impella RP device. The device is inserted percutaneously. The inflow portion of the catheter resides in the inferior vena cava, and a flexible cannula traverses the right atrium, tricuspid valve, and pulmonic valve. The outflow portion of the catheter resides in the main pulmonary artery.
Source: Abiomed.

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CHAPTER 26

Transcatheter Edge-to-Edge Repair of the Mitral Valve

Patrick Kietrsunthorn, Aaron Schelegle, Duong B. Huynh, and Jason Foerst

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

CHALLENGES

Mitral transcatheter edge-to-edge repair (mTEER) is the only FDA-approved approach to treat native mitral valve regurgitation for patients with appropriate anatomy at high risk for surgical mitral valve repair/replacement [1]. While originally approved in the United States for treatment of degenerative mitral regurgitation (DMR), mTEER has further proved to be the most effective treatment of functional mitral regurgitation (FMR) in patients with reduced left ventricular systolic function and dilated annulus [2, 3]. Both the MitraClip system (Abbott Vascular, Santa Clara, CA, USA) and PASCAL system (Edwards Lifescience, Irvine, CA, USA) are FDA-approved mTEER systems. The PASCAL system is only currently approved for the treatment of DMR as of 2024.

Today, one of the challenges is understanding the limitations of mTEER in various mitral valve anatomies. The goal of mTEER should be to resolve as much MR as possible while maintaining adequate residual orifice to prevent clinically significant stenosis. Anatomies with severe mitral annular calcification (MAC), pre-existing stenosis, broad MR jets, or commissural jets may prove challenging. Multiple transcatheter mitral valve replacement (TMVR) devices are in clinical trials and may ultimately prove to be a better option in these complex anatomies [4].

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GAME PLAN

In the United States, mTEER is performed under general anesthesia with transesophageal echocardiography (TEE) guidance, although 3D intracardiac echocardiogram guidance has also been utilized as a standalone or complementary imaging modality [5]. Baseline TEE images should be used to identify the optimal septal crossing location, severity, and mechanism of MR with measurement of pulmonary vein flow and 3D assessment of the location of the proximal isovelocity surface area (PISA) to determine the precise location for optimal grasping, assessment of the mitral valve gradient and mitral valve area, and ruling out thrombus in the left atrial appendage (LAA).

Anatomic requirements The mitral valve is a complex structure with multiple components, including the anterior and posterior mitral valve leaflets, the mitral valve annulus, and the subvalvular apparatus. The posterior mitral valve leaflet is narrow and crescent–shaped, while the anterior leaflet is broad in the center and narrow at the commissures to approximate the posterior leaflet. The posterior mitral valve leaflet has indentations separating the leaflet into 3 scallops (P1 on the lateral side, P2 in the center, and P3 on the medial side). The anterior mitral leaflet has less pronounced indentation but is labeled A1, A2, and A3 to reflect the anatomy of the posterior leaflet. The width of both leaflets (especially the posterior leaflet) becomes narrower toward the commissures, which may be an obstacle to mTEER due to inadequate leaflet length for grasping.

The mitral valve annulus is a saddle-shaped ring with the anterior and posterior aspects higher than the medial and lateral commissures. The anterior portion of the mitral valve annulus connects the anterior mitral leaflet to the aortic annulus, while the posterior mitral annulus connects the posterior mitral leaflet to the left atrial and left ventricular myocardium. The posterior portion of the mitral annulus is more dynamic during systole and diastole as compared to the anterior portion, which might account for the increased incidence of MAC developing in the posterior annulus.

Lastly, the subvalvular apparatus consists of the posteromedial papillary muscle with chordae attaching to the medial aspect of both mitral valve leaflets and the anterolateral papillary muscle with chordae attaching to the lateral aspect of both mitral valve leaflets [6]. The density of the chordae increases toward the lateral and medial commissures, which increases the risk of device entanglement during mTEER.

Patient selection Several anatomic factors should be considered when selecting an appropriate candidate for mTEER. These anatomy types can be categorized into optimal, suitable, challenging, and unsuitable anatomy (Figure 26.1). MR location is important, as commissural MR tends to have a shorter posterior leaflet length, which can result in poor leaflet grasp and single leaflet device attachment (SLDA). Additionally, the density of the subvalvular apparatus increases toward the commissures, increasing the risk of device entanglement. Multiple MR locations usually require more than one clip for treatment, which can increase the risk of mitral stenosis. To further assess this risk, the mitral valve area can be measured under TEE to help with decision-making in terms of the number of clips that can be safely deployed. If the risk of mitral stenosis is high, it may be prudent to accept some residual regurgitation with one device than have mitral stenosis because of multiple devices.

Calcification of the mitral valve is a major obstacle to mTEER due to poor leaflet grasping and limited leaflet mobility for leaflet approximation. MR associated with MAC usually occurs at the location that is most heavily calcified, making it very difficult to have an appropriate grasp of the thick and non-pliable leaflet. Additionally, MAC is also associated with reduced MVA and elevated gradients across the mitral valve, which increases the risk of mitral stenosis after device deployment. Similarly, mTEER of thick and restricted rheumatic leaflets shares the same concerns.

	Optimal anatomy	Suitable anatomy	Challenging anatomy	Unsuitable anatomy
MR location	Central A2/P2	Commissural	Multiple segments	Cleft or perforation
Mitral valve area (planimetry)	>4 cm^2	>3 cm^2	>3 cm^2	<3 cm^2 Mean gradient > 5 mmHg
Posterior leaflet length	>10 mm	7–10 mm	6–7 mm	<6 mm
Leaflet characteristic	Noncalcified Normal leaflet mobility and thickness	Calcification outside grasping zone Increased leaflet mobility and thickness	Partial calcification of the grasping zone Annuloplasty ring HOCM Excessive leaflet mobility and thickness (Barlow's disease)	Extensive calcification involving the grasping zone Rheumatic thickening and restrictive leaflet motion
Tenting height (secondary MR)	<11 mm	>11 mm	>11 mm	>11 mm
Flail width (primary MR	<15 mm	>15 mm	>15 mm	>15 mm
Flail gap (primary MR)	<10 mm	<10 mm	>10 mm	>10 mm

Figure 26.1 Anatomic characteristics for consideration during transcatheter edge-to-edge repair of the mitral valve (mTEER). Source: Transcatheter Edge-to-Edge Repair / Society for Cardiovascular Angiography and Interventions

The tenting height is the distance between the tip of the leaflet and the mitral annular plane during systole. When the left ventricle (LV) dilates in FMR, the mitral valve leaflets become more restricted and displaced apically away from the mitral annular plane. As LV dilation worsens, the leaflets become more restricted leading to an increase in tenting height and vena contracta making it more challenging for mTEER. This was more of a problem with the early-generation mTEER device during the Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients With Functional Mitral Regurgitation (COAPT) trial; however, with the advent of longer device arms and independent leaflet grasping, this has been less of an obstacle. Lastly, the flail gap and flail width are important parameters when evaluating DMR. The larger the flail gap (vena contracta) and the flail width (longitudinal width of the flail segment along the closure line of the mitral valve), the more difficult it is to treat (Figure 26.2). A larger flail gap will require longer grasping arms in order to ensure sufficient leaflet grasping to prevent SLDA. A larger flail width will require a wider device or multiple devices to fully cover the entire width of the flail segment. In cases of severe prolapse/flail, multiple devices may improve stability.

Procedural Details

Patients typically undergo general anesthesia to allow for TEE guidance of the mTEER procedure. Radial artery access for invasive arterial pressure monitoring is also important to ensure hemodynamic stability during the procedure. MR severity also correlates with the systolic blood pressure, and therefore it is important to assess the degree of MR while having accurate

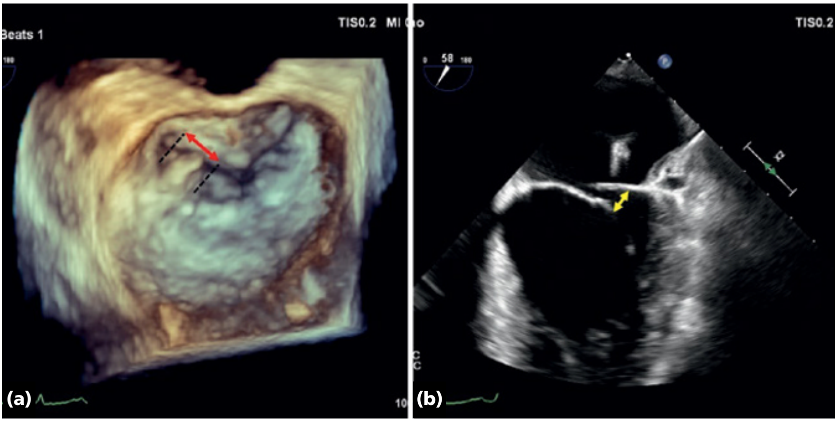


Figure 26.2 Identification of the flail width and flail gap. (a) Flail width (red arrow). (b) Flail gap (yellow arrow).

real-time systolic blood pressure monitoring. The right groin is the access site of choice for mTEER and should be prepped and draped in the usual sterile fashion. Heparin should be given at 100 units per kg to achieve an activated clotting time (ACT) of >250 seconds. We like to give heparin prior to the start of the procedure after TEE confirms no thrombus in the LAA to minimize delays, but some operators may elect to give heparin after venous access or transseptal puncture.

Venous access Venous access should be performed at the mid femoral head under fluoroscopic and ultrasound guidance. When choosing a target for puncture under ultrasound, be cognizant of valves in the venous system, as these structures can hinder the proper deployment of the Perclose device (Abbott Vascular, CA, USA). Access should be performed with the Seldinger technique with the goal of front wall puncture. The tract is dilated with a 6-F sheath and ACT is drawn. The 6-F sheath is removed, and two perclose devices are deployed in the usual "preclose" fashion at 10–2 o'clock. Once the second "preclose" is performed, we proceed to transseptal puncture.

Transseptal puncture The ideal location for transseptal puncture is superior and posterior. First, the fossa is visualized in the bicaval view for the superior position and then at the aortic valve short axis view for the posterior position (Figure 26.3). Prior to puncture, the 4-chamber mid-esophageal view (typically 0°) is used to measure the distance from the mitral valve annulus to the plane of transseptal puncture. The ideal height above the annulus should be 4.0–4.5 cm (Figure 26.3). The choice of transseptal crossing system is operator dependent; however, most operators prefer the precision of a radiofrequency (RF) energy needle. Experienced operators will fine-tune this height based on the pathology such that medial MR is addressed with a slightly higher puncture (4.5 cm), while lateral jets may be better served with a slightly lower puncture (3.5–4 cm) (Figure 26.4) [7].

MitraClip system The MitraClip system is composed of a steerable guide catheter (SGC), clip delivery system (CDS), and stabilizer that secures the system in place over the patient's thigh (Figure 26.5). The MitraClip itself is now in the fourth generation (G4) with independent gripper motion and four sizes: NT, NTW, XT, and XTW (Figure 26.6). The most commonly used size for the initial clip is the XTW, which is the widest and longest of the four.

Following transseptal puncture, a stiff guidewire is delivered to the left atrium (LA). We typically use a pigtail wire, such as the Versacross wire (Boston Scientific, Minneapolis, MN), for

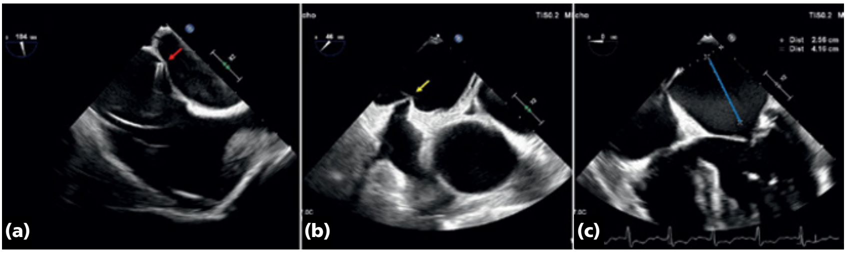


Figure 26.3 Explanation of the ideal transseptal crossing. (a) Aim for a superior or mid site puncture in the bicaval TEE view (red arrow), (b) aim for a posterior or mid site puncture in the aortic short axis view (yellow arrow), and (c) final goal is 4–4.5 cm above the mitral annulus (blue line).

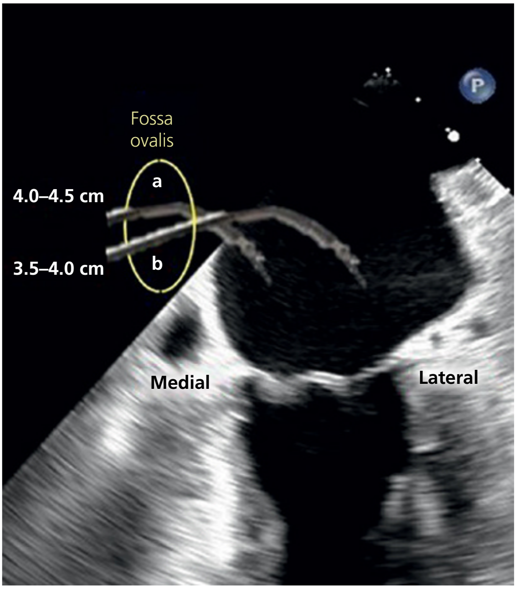


Figure 26.4 Targeting specific transseptal heights for commissural jets. (a) Aim higher for medial jets and (b) lower for lateral jets.

both the crossing wire/needle and for delivery of the SGC. Prior to inserting the SGC into the body, the knob should be turned to the "−" direction to straighten out the tip of the catheter. Once the SGC is in the RA, the knob is returned to the neutral position prior to crossing the septum. It is important to visualize the atrial septum as the SGC is advanced into the LA to ensure that the catheter is across the septum without advancing it too far into the left atrium. Once the guide catheter is tenting the septum, a clockwise and counterclockwise rotation of the guide catheter while keeping gentle forward tension can help it cross into the LA without jumping too far. If there are continued difficulties in crossing the septum, the SGC can be removed and replaced with a large-bore sheath, and balloon septostomy can be performed (e.g. 8 mm × 40 mm peripheral balloon).

Once the SGC is positioned in the LA and the wire and dilator are removed, the side port can be attached to the manifold for de-airing and LA pressure measurements. Next, the CDS is inserted into the SGC, aligning the blue markers for proper "keying" of the system (if this step

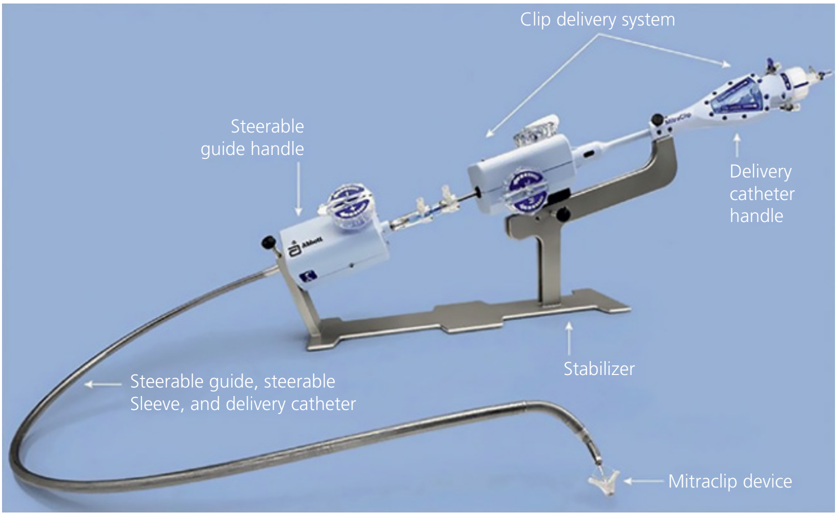

Clip delivery system
Steerable guide handle
Delivery catheter handle
Stabilizer
Steerable guide, steerable Sleeve, and delivery catheter
Mitraclip device

Figure 26.5 MitraClip G4 system composed of the steerable guide catheter (SGC), clip delivery system (CDS), and stabilizer that secures the system in place over the patient's thigh.

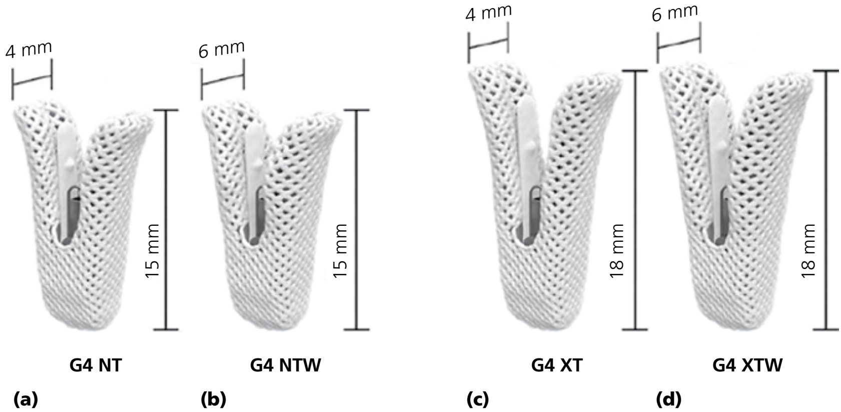
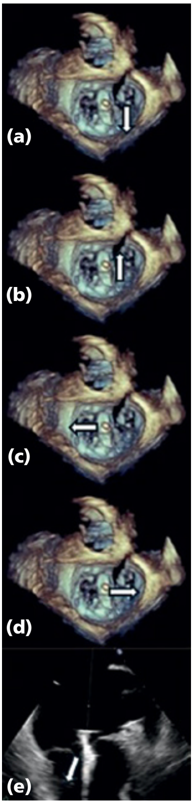

4 mm
15 mm
G4 NT
(a)
6 mm
15 mm
G4 NTW
(b)
4 mm
18 mm
G4 XT
(c)
6 mm
18 mm
G4 XTW
(d)

Figure 26.6 MitraClip G4 device. (a) NT, (b) NTW, (c) XT, and (d) XTW.

is not performed properly, there may be difficulties in maneuvering the clip in the usual fashion). The CDS is carefully advanced into the LA under TEE guidance to avoid injuring/perforating the lateral wall of the LA. To allow for room in the LA for the CDS, the SGC can be withdrawn so that the tip is 1–2 cm across the septum. Advance the CDS until the radiopaque ring at the tip of the SGC is centered between the radiopaque alignment marker on the CDS (referred to as "straddling the device"). Next, the clip is maneuvered down to the mitral valve by turning the "M" knob to move the CDS medially as the SGC is being rotated posteriorly. This should be done under TEE guidance to safely clear the Coumadin ridge and the LAA. At this time, 3D TEE of the mitral valve can help align the clip to the target location.

The clip can be maneuvered anteriorly by counterclocking the SGC, posteriorly by clocking the SGC, laterally by advancing the entire system, and medially by withdrawing the entire



Rotate SGC clockwise for posterior

Rotate SGC counter clockwise for anterior

Advance SGC to move laterally

Withdraw SGC to move medially

M knob flexes medially

Figure 26.7 Maneuvering the MitraClip in the left atrium. (a) Steerable guide catheter (SGC) clockwise for posterior rotation, (b) SGC counterclockwise for anterior rotation, (c) advance the SGC for lateral translation, (d) withdraw the SGC for medial translation, and (e) M knob for medial flexion.

system. If the CDS is too close to the mitral valve, the "A" knob can be used to gain height, which will maneuver the CDS superiorly and anteriorly (to counter the anterior of the "A" knob, the SGC can be rotated posteriorly and/or the "M" knob can be increased). If the CDS is too far away from the mitral valve, the "P" knob can be used to lose height. The "P" knob will maneuver the CDS in the opposite direction of the "A" knob, and therefore the SGC rotation and "M" knob rotation should be done in the opposite direction. If the CDS is too close to the aorta ("aorta hugger"), the "+" knob on the SGC can be used to move the CDS more posteriorly (Figures 26.7 and 26.8). Once the CDS is maneuvered into the target location, the clip arms are opened to 120° to ensure that the clip is aligned perpendicular to the closure line of the mitral valve (note the angle may change near the commissures). The alignment of the clip arms can be adjusted by clocking or counterclocking the CDS while using small forward/backward motion to transfer the torque [8].

Once the CDS is at the desired location in the correct orientation, slowly advance the CDS toward the mitral valve to ensure that the trajectory of the CDS is perpendicular to the line of coaptation. Next, advance the CDS into the left ventricle under TEE guidance in the bicommissural (bicom) view and the LVOT view (this can be seen simultaneously by X-planing the clip in the bicom). The bicom view shows the medial/lateral plane of the mitral valve, while the LVOT view will show the anterior/posterior plane of the mitral valve (Figure 26.9). Once the correct

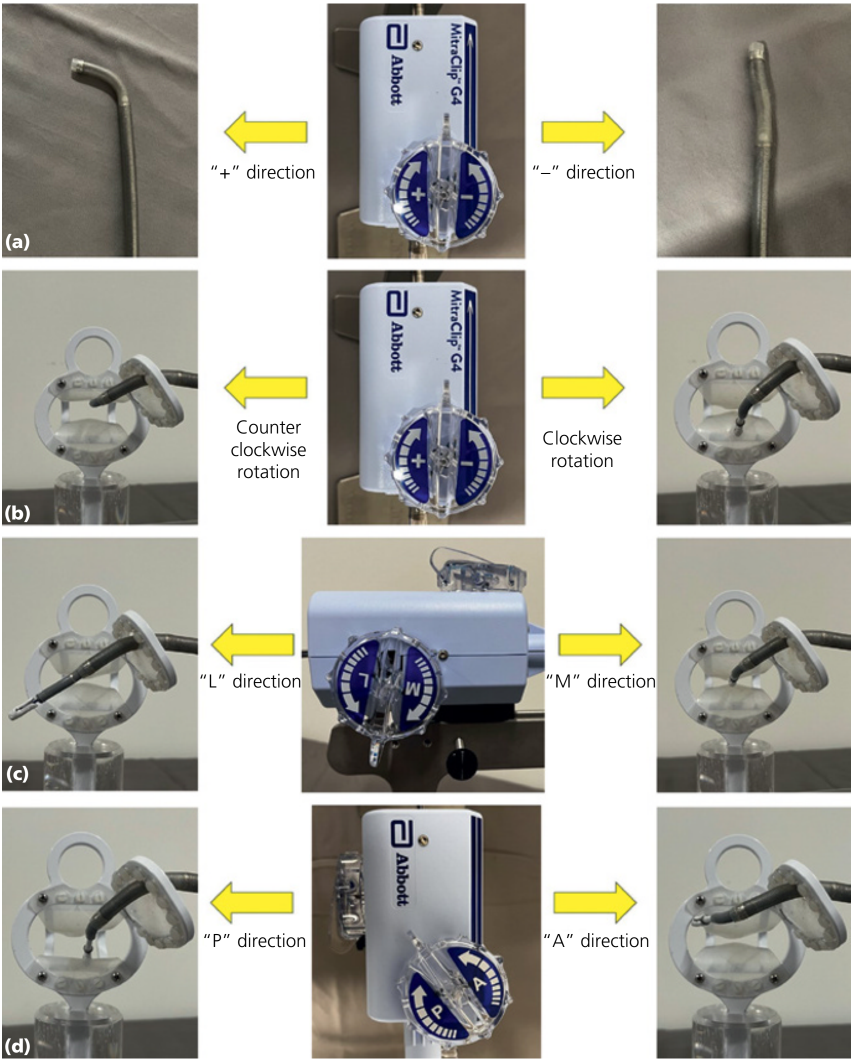

(a)
"+" direction
"–" direction
(b)
Counter clockwise rotation
Clockwise rotation
(c)
"L" direction
"M" direction
(d)
"P" direction
"A" direction
MitraClip G4
Abbott

Figure 26.8 Maneuvering the MitraClip with the knobs. (a) Steerable guide catheter knob "+" direction to increase and "−" direction to decrease the tip flexion. (b) Clockwise rotation of the steerable guide catheter to move the MitraClip posterior and counterclockwise to move the MitraClip anterior. (c) Clip delivery system M/L knob used to flex or straighten the tip of the clip delivery system. (d) Clip delivery system PA knob used to lose height and gain height.

location and orientation of the clip are again confirmed, the CDS is withdrawn back toward the mitral valve. Once the mitral valve leaflets are positioned inside the clip arms, the grippers are dropped to capture the leaflets (this can be done together or one at a time). The clip arms are then closed while the CDS is advanced slightly to re-introduce some slack into the mitral valve. As the clip arms are being closed, it is helpful to put color over the mitral valve to see the improvement in MR in real time. Ensure that the blood pressure is in the normal range by

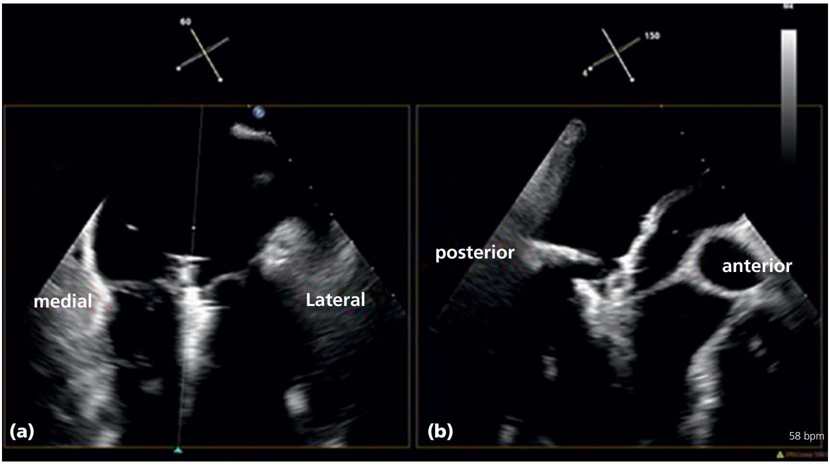


Figure 26.9 Grasping view. (a) The commissural view is used to identify medial versus lateral clip position and (b) the long axis view is used to identify anterior and posterior clip position.

administering pressors if necessary to ensure that the MR is not artificially reduced due to hypotension. Leaflet insertion should now be confirmed with the following: 3D en face imaging to demonstrate tissue bridging, LVOT or 0° view to confirm leaflet tissue is over the clip arm, and assessment of mitral valve gradient. Pulmonary vein flow improvements can also help to ensure a good hemodynamic response.

If the clip needs to be repositioned, the clip arms can be opened, and the grippers lifted. For A2/P2 position, small maneuvering of the CDS can be considered while the clip is below the valve; however, if large maneuvering is planned or if the clip is in the A1/P1 or the A3/P3 position, the clip arms should be inverted and withdrawn back into the LA prior to maneuvering to reduce the risk of entanglement with the subvalvular apparatus.

Once the clip is closed and grasping is confirmed at the target location on the mitral valve, the device-releasing sequence can be initiated. First, test the lock of the clip by opening and closing the clip while in the lock position to make sure the clip arms do not move. Next, expose the gripper line at the end of the lock lever and slowly remove the line by pulling one end of the string. Then remove the "pin" and turn the arm position wheel toward the open direction to expose the groove at the end. Once the groove is exposed, turn the acorn in the counterclockwise direction 8 rotations, and the acorn is pulled back to finally release the clip. Once this is done, pull the gripper arms back, slide the CDS handle back, and then reverse the "M" knob and withdraw the tip of the CDS back into the SGC and outside the body.

PASCAL precision system The PASCAL Precision system for mTEER has several nuances to distinguish itself from the MitraClip. The delivery system itself is somewhat similar, with a steerable guide sheath (GS) independent of the steerable implant system, which is composed of the steerable catheter (SC) and the implant catheter (IC), which controls the PASCAL implant. There are two versions of the PASCAL implant. The original PASCAL device is wider, and the PASCAL ACE device is thinner. Both of the implants have a central nitinol spacer that is designed to minimize tension on the mitral leaflets (Figure 26.10). Like the MitraClip G4 system, the grippers can be moved independently to grasp either both leaflets simultaneously or one at a time. There is only a single row of teeth on the gripper as opposed to the MitraClip with multiple rows. During deployment, the device can be fully extended rather than inverted when trying to reposition, which ideally minimizes cord entanglement.

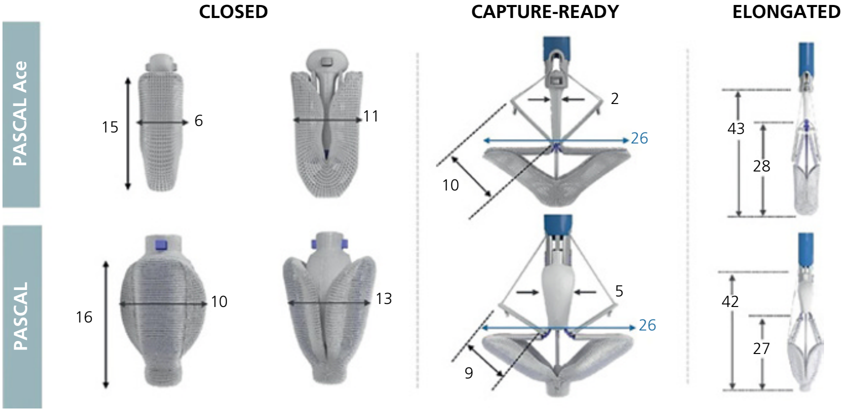


Figure 26.10 PASCAL and PASCAL ACE device.

The GS flex knob is the equivalent MitraClip +/- knob to allow correcting for "aorta hugging." Rotation clockwise on the GS will stand the system up higher above the mitral valve, similar to A knob on the MitraClip.

The steerable catheter allows medial/lateral translation as well as anterior/posterior translation. In order to move more anterior with the PASCAL Implant, the SC is rotated counterclockwise and clockwise for posterior. The SC can be advanced laterally and retracted medially for positioning in the valve. The SC flex knob is rotated clockwise for medial trajectory, similar to the M knob on the MitraClip (Figure 26.11).

Once a stiff guidewire is placed in the LA, the guide sheath is advanced into the RA. Slowly advance the guide sheath into the LA under TEE guidance. Once in place, place the guide sheath in the first stabilizer of the stabilizer rail system (SRS). The stabilizers have a lock and unlock position. Once the guide sheath is in place, the wire and dilator are removed. Next, the implant system is advanced (SC and implant catheter) past the seals of the GS. At this point the loader is retracted and the GS is aspirated and flushed. Continue to advance the Implant System through the GS until the implant is at the distal tip. Mount the SC and the implant catheter onto the second and third stabilizers on the SRS. The implant is loaded through the GS in its elongated position and should be closed once out of the guide sheath. Once the implant is closed, retract the clasp sliders. Under TEE guidance, advance the SC and turn the flex knob clockwise to flex the implant down toward the mitral valve. Do this in a stepwise fashion, being sure to avoid injuring LA structures such as the Coumadin ridge and the LAA.

The implant can be maneuvered anteriorly by counterclocking the SC, posteriorly by clocking the SC, laterally by either advancing just the SC or the entire system, and medially by withdrawing just the SC or the entire system. Once the implant is maneuvered to the target location, turn the knob on the implant catheter counterclockwise to open the paddles to the leaflet-capture-ready position. Individually advance and retract one clasp slider at a time to identify which slider controls which clasp. Rotate the implant catheter to align the paddles perpendicular to the closure line of the mitral valve. Advance the implant catheter until the paddles are below the free edge of the leaflets. This should again be done with TEE guidance using the bicommissural view and the LVOT view as mentioned in the MitraClip section. Retract the implant catheter until the mitral valve leaflets are lying flat on the paddles. Advance the clasp sliders to drop the clasps onto the paddles and capture the leaflet. This can be performed

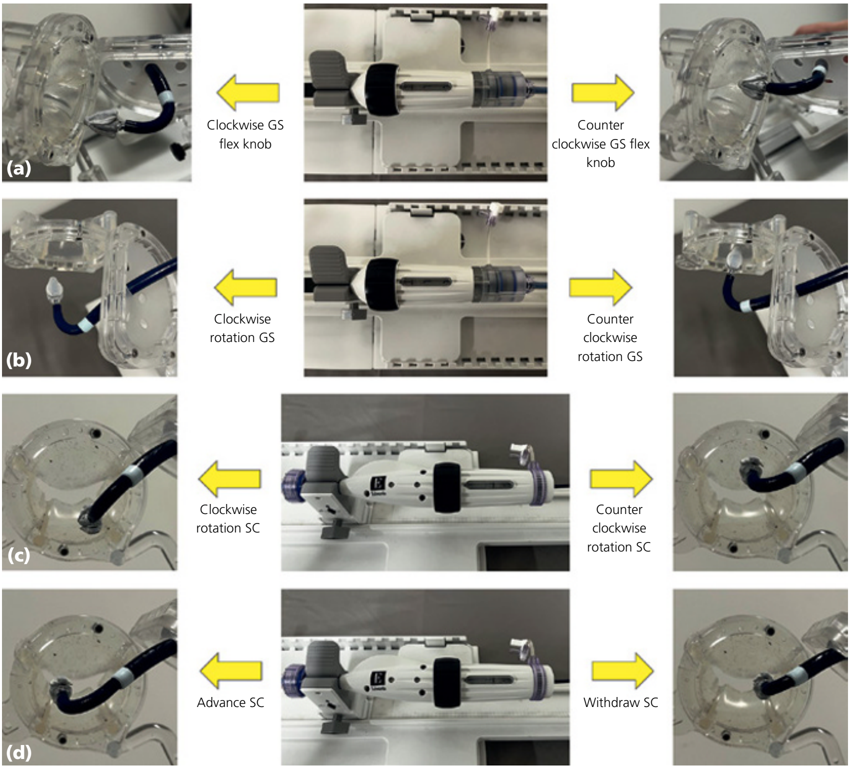


Figure 26.11 Maneuvering the PASCAL device. (a) Clockwise rotation of the guide sheath knob directs the system posterior to correct for "aorta hugging" and vice versa in the clockwise–counterclockwise direction. (b) Clockwise rotation of the guide sheath will increase height, while counter clockwise will decrease height. (c) Clockwise rotation of the steerable catheter will direct the PASCAL device posterior, while counterclockwise rotation will direct the PASCAL device anterior. (d) Advancing the steerable catheter will move the PASCAL device laterally, while withdrawing the steerable catheter will move the PASCAL device medially.

for each leaflet separately if the leaflets are far apart and appropriate grasping of the leaflet cannot be done simultaneously. Once the leaflets are secured, close the paddles by turning the knob on the implant catheter clockwise. As the implant is being closed, advance the implant catheter slightly to release any tension on the leaflets. If repositioning in the ventricle is required, retract the clasp sliders and set the paddles back to the leaflet-capture-ready position. If repositioning in the atrium is required, retract the clasp sliders and elongate the implant by turning the knob on the implant catheter counterclockwise. Elongation should be done under fluoroscopy and echo guidance to ensure no bending or tension in the system. Once fully elongated, retract the implant back into the atrium.

Once the implant is at the target location with satisfactory MR reduction, the implant can be released. Unscrew and remove the implant release cover from the implant catheter. Unthread and remove the suture lock on each side of the implant release knob. Rotate the implant release knob counterclockwise until the implant is released. Retract the implant catheter into the SC. Unflex the implant system and remove it from the LA.

ABBREVIATIONS

DMR	Degenerative mitral regurgitation
FMR	Functional mitral regurgitation
TEE	Transesophageal echocardiography
mTEER	Mitral transcatheter edge-to-edge repair
LA	Left atrium
RA	Right atrium
SGC	Steerable guide catheter (MitraClip)
CDS	Clip delivery system (MitraClip)
LV	Left ventricle
SLDA	Single leaflet device attachment
MAC	Mitral annular calcification
SRS	Stabilizer rail system (PASCAL)
GS	Guide sheath (PASCAL)
SC	Steerable catheter (PASCAL)
IC	Implant catheter (PASCAL)
LAA	Left atrial appendage

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CHAPTER 27

Transcatheter Cardiovascular Electrosurgery

Jason Foerst, Patrick Kietrsunthorn, James Livesay, Aaron Schelegle, and Adam Greenbaum

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⧗, <10 min extra; ⧗⧗, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

CHALLENGES

The field of structural cardiology has dramatically matured since the Food and Drug Administration (FDA) approval of transcatheter aortic valve replacement (TAVR) in December of 2011. Despite these advances, limitations with commercially approved devices have precluded treatment of many patients. Electrosurgical techniques have been iteratively developed to tackle many of the limitations of commercial therapies. Electrosurgical procedures have in common using “off-the-shelf” catheters and wires to lacerate cardiac tissue, traverse occlusions, or traverse tissue planes in the body using radiofrequency energy to enable more traditional treatment options [1]. Examples include transcaval access to

(*Continued*)

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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allow alternate access for large-bore arterial catheters, bioprosthetic or native aortic scallop intentional laceration to prevent iatrogenic coronary artery obstruction during TAVR (BASILICA) to prevent obstruction of coronary arteries, and laceration of the anterior mitral leaflet to prevent outflow obstruction (LAMPOON) to prevent obstruction of the left ventricular outflow tract during transcatheter mitral valve replacement (TMVR).

GAME PLAN

While increasingly common, electrosurgical procedures do require a foundation of knowledge of the principles of delivering radiofrequency energy through insulated wires, careful procedural planning, and multiplane procedural visualization. Unfortunately, these procedures are still considered "off-label," and therefore formal proctoring is challenging. Many have obtained these skills via formal structural heart fellowships or through case observations at participating centers.

TRANSCAVAL ACCESS

One of the first formally studied electrosurgical procedures is transcaval access to allow large-bore catheters to reach the aorta in the setting of advanced peripheral artery disease [2]. This procedure uses the basic physiological principle that blood will travel from the highest pressure to the lowest pressure in a closed system (Figure 27.1). In this case a puncture is made from the inferior vena cava into the abdominal aorta with the knowledge that the pressure of the fluid in the retroperitoneal space is higher than the venous pressure. The transcaval investigational device exemption (IDE) study and follow-up comparison studies have demonstrated an excellent safety profile with a lower risk of stroke than other forms of alternative access.

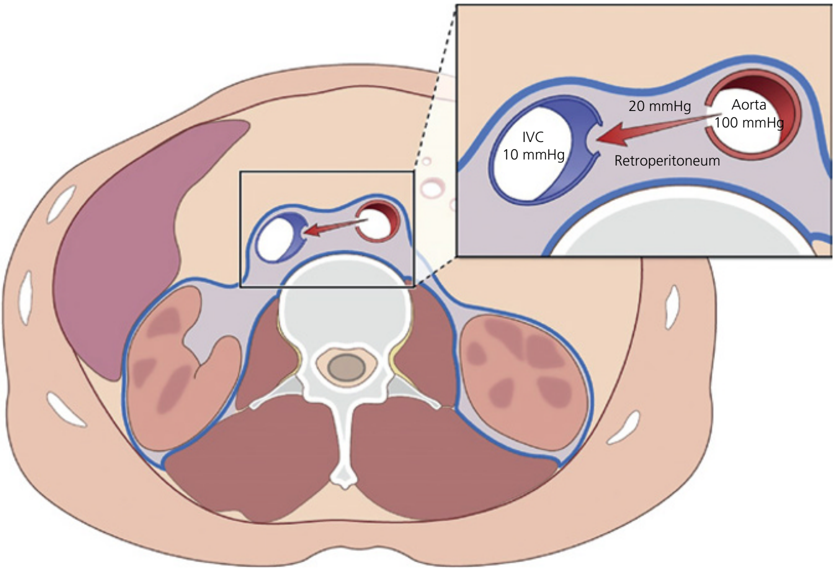

Figure 27.1 Transcaval access principle: Blood will travel from the highest pressure to the lowest pressure in a closed system [3].

Tips and Tricks

Procedural planning with a contrasted abdominal CT will ideally identify a calcium-free window along the medial abdominal aorta that is 2 cm below the renal arteries and 2 cm above the iliac bifurcation should a bailout stent be required. Venous access is obtained in the right femoral vein, and a renal length 6-F internal mammary (IM) or renal double curve (RDC) (1) catheter is advanced to the pre-selected vertebral level based on the CT scan. A 6F sheath is placed in the common femoral artery with the least amount of iliofemoral disease (should a bailout be required), and a 6F JR4 guide is advanced to the preselected vertebral body within the abdominal aorta. A gooseneck snare sized to the aorta is then advanced through the arterial guide and positioned parallel to the medial aortic wall to serve as a target for the traversal wire (Figure 27.2) [3]. The mother-daughter traversal system is then advanced through the venous catheter. This system is composed of an Astato XS 20 0.014″ wire inside an 0.014″ microcatheter [e.g. Finecross (Terumo Interventional Systems, Tokyo, Japan)] or Piggyback wire (Teleflex, Wayne, PA, USA) converter inside an 0.035″ microcatheter [e.g. Navicross (Terumo Interventional Systems, Tokyo, Japan)]. The back end of the Astato XS 20 wire (Asahi, Aichi, Japan) is denuded and clamped to an electrosurgical pencil set to 30–50 watts "pure cut," depending on the specific diathermy unit utilized. Once the venous catheter is positioned appropriately to the center of the aorta (snare), then the wire is advanced while applying "cut mode" energy. The wire is then snared and advanced to the thoracic aorta, over which the 0.014″ microcatheter/Piggyback wire converter is advanced, and then 0.035″ microcatheters are advanced (Figure 27.3). Once in place, the snare is released, and 0.014″ wire and microcatheters are removed from the 0.035″ microcatheter in place of a Lunderquist 0.035″ wire (Cook Medical Inc., Bloomington, IN, USA). The catheters are then removed, and the large bore sheath is advanced under fluoroscopy across the cava/aorta. In cases where there is difficulty advancing either of the catheters, high-pressure balloon dilation of the aortic wall with a 2.5 mm noncompliant coronary balloon over the 0.014″ wire will facilitate catheter advancement.

Once the intended procedure is complete [e.g. TAVR or Impella (Abiomed, Danvers, MA, USA)], then protamine is administered and the aortotomy is closed using a 10/8 Amplatz duct occluder for 14- to 18-Fr sheaths and 12/10 for larger sheaths or Impella access that has been in for more than 24 hours. Protamine would be administered prior to deployment of the occluder. The closure is then assessed by aortogram to determine residual leak (Figure 27.4). Type 0 means no leak. Type 1 means mild residual shunt. Type 2 means a small amount of extravasation but not extending into the retroperitoneum. Type 3 means extravasation into the retroperitoneum. Type 2 and 3 leaks should initially be treated with an oversized aortic occlusion balloon at low pressure for 3–5 minutes. If there is a residual leak after a few sequential balloon inflations, then a covered stent is indicated. In our experience, the rate of Type 0 closure is 75%, and the rest have been mitigated with balloon occlusion.

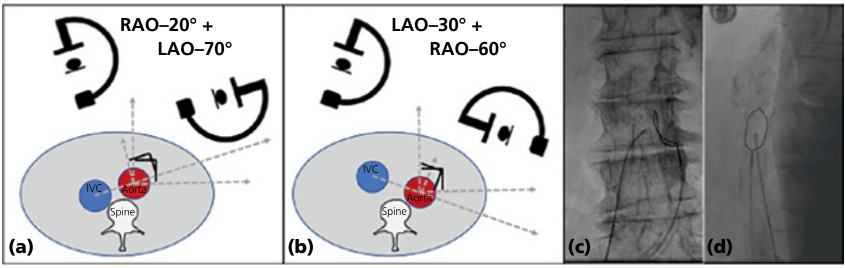

Figure 27.2 Transcaval access: (a) Typical cross-sectional relationship of inferior vena cava (IVC), aorta, and spine. Vessel center points define frontal right anterior oblique (RAO) and conjugate enface left anterior oblique (LAO) projections. (b) Less common aorta/IVC location, with attendant LAO frontal and conjugate RAO en face projections. (c, d) Representative frontal (c) and en face (d) projections (Source: From Lederman et al. [3] / Elsevier / CC BY 4.0).

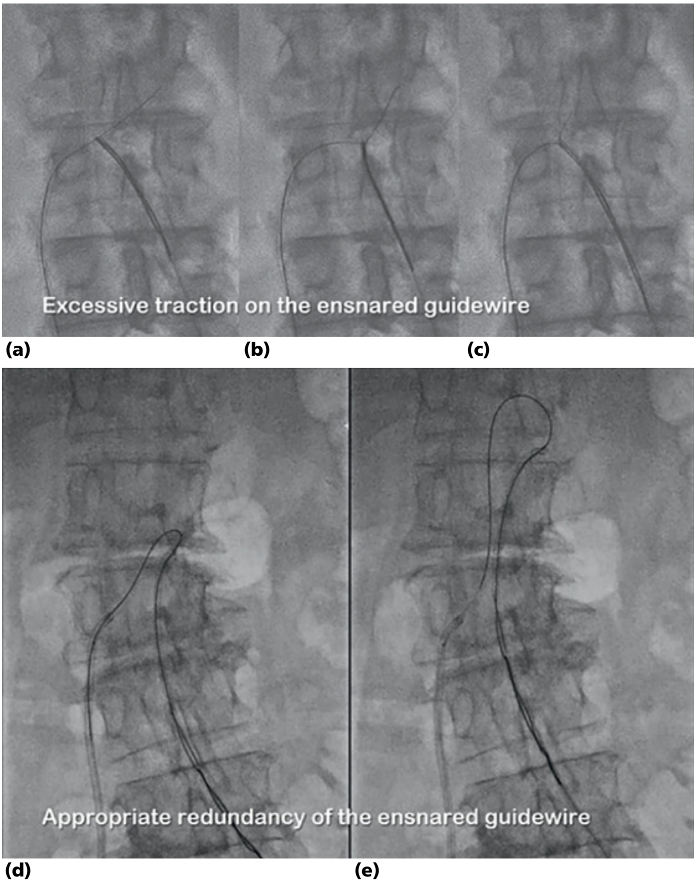
Excessive traction on the ensnared guidewire
(a)
(b)
(c)
Appropriate redundancy of the ensnared guidewire
(d)
(e)

Figure 27.3 Transcaval access: (a to c) Excessive traction on the ensnared guidewire may pull the guiding catheter outwards (c), risking aortic perforation. (d) If the guidewire is fed toward the aorta during snare invagination, the guiding catheter does not jump. (e) Redundant guidewire safety loops avoid aortic injury during advancement. Source: From Lederman et al. [3] / Elsevier / CC BY 4.0.

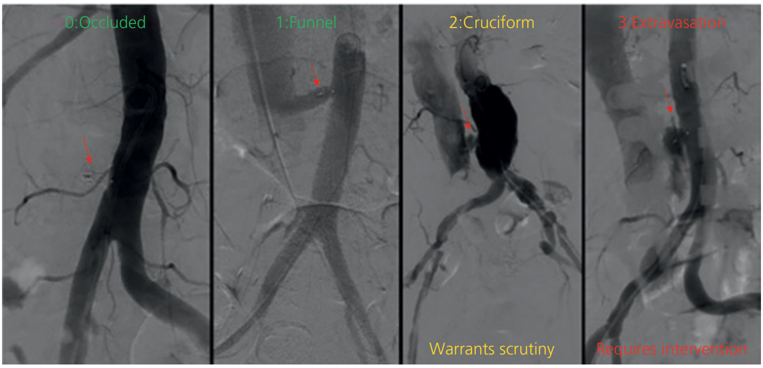
0:Occluded
1:Funnel
2:Cruciform
3:Extravasation
Warrants scrutiny
Requires intervention

Figure 27.4 Transcaval closure patterns on completion aortography: Patterns of completion aortograms: complete occlusion ("type 0"), funnel ("type 1"), and cruciform ("type 2") patterns are functionally equivalent and reflect laminar (funnel) or vorticial (cruciform) blood flow. Cruciform patterns require digital subtraction angiography to ensure no extravasation ("type 3") warranting immediate treatment. Source: From Lederman et al. [3] / Elsevier / CC BY 4.0.

BIOPROSTHETIC OR NATIVE AORTIC SCALLOP INTENTIONAL LACERATION TO PREVENT IATROGENIC CORONARY ARTERY OBSTRUCTION DURING TAVR (BASILICA)

While TAVR is typically straightforward, there are instances, especially with valve-in-valve TAVR, where the leaflets of the native or bioprosthetic valve will obstruct the coronary arteries or sequester one or both sinuses upon expansion of the transcatheter aortic valve. This is more likely if the coronary artery arises <8 mm above the annulus, small sinuses, or externally mounted surgical valve leaflets. A valve-to-coronary distance is measured in the double oblique view on cardiac computed tomography angiography (CTA) and considered high risk if <4 mm (Figure 27.5) [4]. Historically the only option for these patients would be (redo) surgery or snorkel stenting, which is generally considered high risk for long-term complications. BASILICA allows for laceration of the offending leaflet to prevent obstruction upon expansion of the transcatheter valve.

Tips and Tricks

Building on the tools for transcaval, BASILICA utilizes a stiff 0.014" wire (e.g. Astato XS 20) and a 0.014" microcatheter inside a guide catheter for insulation to penetrate the culpable aortic leaflet as basally as possible and then snare the wire in the left ventricle and externalize it after forming the quintessential "flying V," which is the lacerating surface of the wire. Finally, the two guiding catheters are pulled simultaneously while electrifying the wire with an electrosurgical pencil to lacerate the offending leaflet. The side view and en-face views are established a priori by CTA (Figure 27.6).

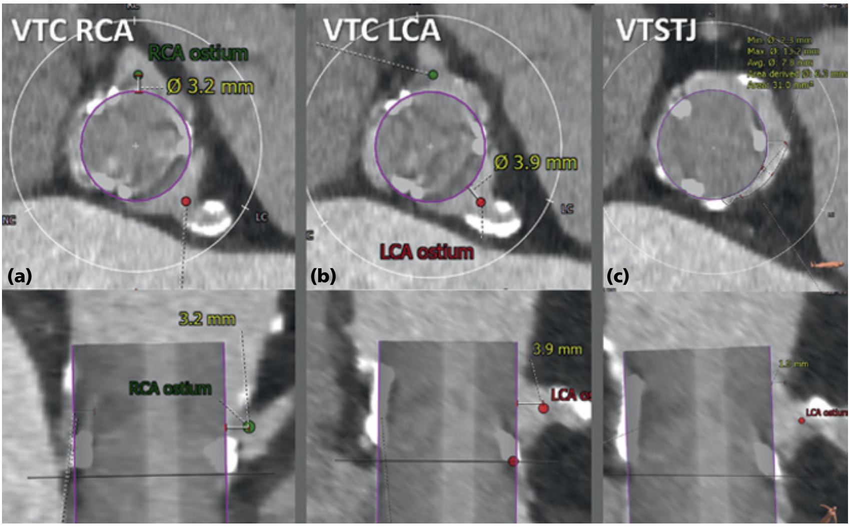

Figure 27.5 Measure virtual valve-to-coronary distance and virtual valve-to-sinotubular junction distance: The virtual valve-to-coronary (VTC) distance is measured in two orthogonal planes (top, axial; bottom, longitudinal). Representative VTC distance measurement for a right coronary artery (RCA) (a) and left coronary artery (LCA) (b). The valve-to-sinotubular junction (VTSTJ) distance is measured in orthogonal planes (c): axial (upper) and longitudinal (lower), when the sinotubular junction is lower than the height of the transcatheter aortic valve replacement device. Source: From Lederman et. al. [4] / with permission of American College of Cardiology Foundation.

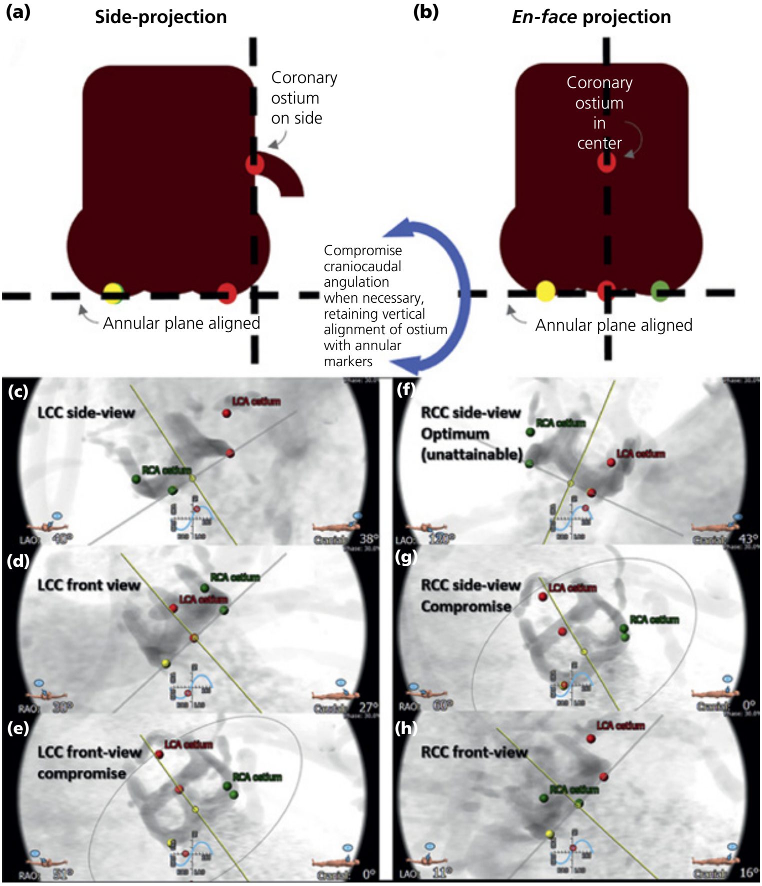
(a)
Side-projection
Coronary ostium on side
Annular plane aligned
(b)
En-face projection
Coronary ostium in center
Annular plane aligned
Compromise craniocaudal angulation when necessary, retaining vertical alignment of ostium with annular markers
(c)
LCC side-view
LCA ostium
RCA ostium
LAO 40°
Cranial 38°
(d)
LCC front view
RCA ostium
LCA ostium
RAO 30°
Cranial 27°
(e)
LCC front-view compromise
LCA ostium
RCA ostium
RAO 51°
Cranial 0°
(f)
RCC side-view Optimum (unattainable)
RCA ostium
LCA ostium
LAO 130°
Cranial 43°
(g)
RCC side-view Compromise
LCA ostium
RCA ostium
RAO 60°
Cranial 0°
(h)
RCC front-view
LCA ostium
RCA ostium
LAO 11°
Cranial 16°

Figure 27.6 Computed tomographic prediction of fluoroscopic projections. First, the annular plane is defined by the 3 annular nadir points (red, left coronary cusp [LCC]; green, right coronary cusp [RCC]; yellow, noncoronary cusp), along with corresponding coronary ostia. (a) The side projection is selected along the annular plane so that the intended annular marker and coronary ostium are on the lateral aspect of the aortic root, and the contralateral annular markers are overlapping. (b) In en face projection, the annular marker and corresponding coronary ostium lie along the centerline of the aortic root, and the annular markers are evenly spaced in a "1-1-1" projection. If either of these projections is fluoroscopically unattainable, the craniocaudal angulation is reduced, while preserving the side or center alignment, until an attainable projection angle is obtained. (Bottom) Representative LCC projections (c to e) and RCC projections (f to h). (c, f) Optimal side views. (d, h) Optimal en face views. (e, g) Compromise projections with reduced craniocaudal. (c-h) Source: From Lederman et. al. [4] / with permission of American College of Cardiology Foundation.

LEFT CORONARY CUSP BASILICA

Typically, a 7 or 8 F AL1-AL4 guide catheter is used to engage the left coronary cusp (LCC) above the leaflet and point down toward the left ventricle on the leaflet's aortic surface. To better align, sometimes a steerable sheath may be helpful in addition to the back end of a standard J-wire to straighten the guide. If further steering is required, then an angled mother-daughter catheter, such as an IM, may be used for another degree of freedom. Once the guide is in place, then the 0.014″ Astato XS 20 is advanced through a 0.014″ microcatheter or Piggyback wire converter to the tip of the guide. The AL guide is positioned in both the side view (initially) and the en-face view. The en-face view will demonstrate if the guide is centered in the LCC to align with the coronary artery, while the side view demonstrates how basal the guide sits.

A second 6F guide is delivered across the aortic valve orifice, typically a 6F JR4 or MP guide through which a gooseneck snare sized 1:1 to the left ventricular outflow obstruction (LVOT) diameter is delivered into the LV and positioned below the LCC as a target for the crossing wire. An 0.018″ wire (e.g. V-18) is used as a safety wire to maintain access to the LV in case the catheter falls back into the aorta.

Next, the back end of the Astato is denuded and connected to an electrosurgical pencil with a hemostat. The electrosurgical pencil is set to pure cut mode and 50 watts, and then with a push of the yellow button (“cut”), the wire is energized and advanced through the leaflet. The wire is then snared in the left ventricle and pulled into the tip of the snare guide. Next, the microcatheter is withdrawn to the back of the Astato, leaving about 3–4 cm, and the “flying V” is formed (Figure 27.7) in front of the microcatheter. Using a scalpel, the wire is bent at a 90° angle, and the inner curve (facing the operator) is denuded 2 mm on either side of the kink. The “flying V” is then advanced through the AL guide to the leaflet tip by advancing the Astato 0.014″ wire while simultaneously pulling on the snare from the opposite guide.

Tips and Tricks

The guides both should have a copilot or Tuohy Borst y-valve to prevent bleeding, and so it is best to disconnect the y-valve and slide it back over the “flying V,” then reconnect once the snare has pulled the “flying V” into the AL guide.

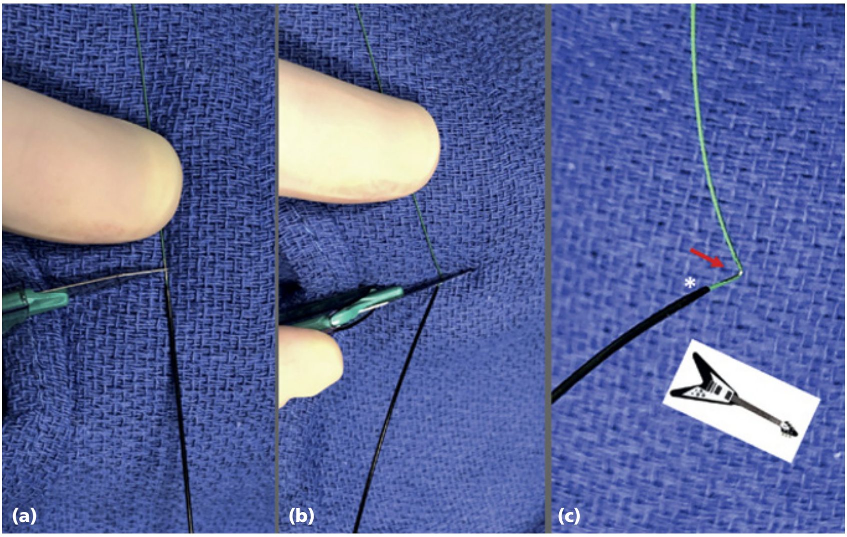

Figure 27.7 Preparation of the “flying V” inner-surface denuded guidewire. (a) Two to three millimeters of guidewire is scraped noncircumferentially immediately distal to the locked Piggyback. (b) Using the back end of the scalpel, the guidewire is kinked against fingers behind a raised towel. (c) Noncircumferential inner-surface denudation (arrow) near the Piggyback in a “flying V” configuration. Source: From Lederman et. al. [4] / with permission of American College of Cardiology Foundation.

When pulling the snared portion of the wire back out of the snare guide, it is best to make sure the snare introducer is advanced through the y-valve (e.g. co-pilot) to prevent the wire from being pulled out of the snare as it exits the guide.

Once the “flying V” is aligned with the leaflet, the Astato XS 20 is secured with torquers on both ends, and tubing is connected to the Y-valves for each guide such that 5% dextrose saline (D5W) can be injected to the guide tips at the time of laceration to improve conduction of the electrical current to the leaflet. The slack is removed from both guides pulling toward the inner curve of the aorta; the guides are positioned such that they are within 5 mm of the “flying V” to ensure proper insulation of the electrical current. Finally, in sequence, the D5W is injected, the electrosurgical pencil is applied on cut mode with 70 watts, and both guides are pulled simultaneously to lacerate the leaflet.

CAUTION

There may be more tension on if there is heavy leaflet calcification. For porcine leaflets, it may be easier to avulse the leaflet with too much force, so the electrical laceration is key and should not require much force.

The Astato is then pulled back through (we usually pull on the AL side), the snare is removed, the guides are removed, and TAVR is performed. We generally take a final selective angiogram of the coronary artery to ensure appropriate filling.

RIGHT CORONARY CUSP BASILICA

The right coronary cusp **(**RCC) laceration can frequently be more challenging than the left due to the difficulty getting the appropriate side view fluoroscopic angle, as it tends to be much steeper. This may require a compromised view (Figure 27.6e,g). We typically use a JR4 or MP guide catheter for crossing the leaflet and MP for the snare guide. On occasion we have also utilized a deflectable guide to help with aligning the crossing guide. Otherwise, the procedure is the same as mentioned above with the LCC once the proper alignment is achieved.

DOPPIO BASILICA

Sometimes both coronary arteries are at risk, and there is a need to lacerate both the right and left coronary leaflets. This was originally performed simultaneously by using bilateral 14F DrySeal guides (W. L. Gore & Associates, Flagstaff, Arizona) to allow both the crossing and snare guides to be delivered through the same access [5]. Both leaflets are crossed and snared, and then the laceration is performed on both leaflets back-to-back to minimize the possibility of prolonged hemodynamic instability from aortic regurgitation. Interestingly, we have found no significant hemodynamic instability from simply performing the left and right sequentially one at a time, which we believe is because the lacerated leaflets tend to still coapt together during diastole despite the laceration.

BALLOON-ASSISTED BASILICA

For extremely high-risk cases, a broader laceration may be indicated and can be performed by crossing, snaring, and then, before forming the “flying V” and lacerating, a 4.0 mm coronary balloon is used to dilate the leaflet, which widens the penumbra of effect (Figure 27.8). If the coronary artery is of extremely high risk, the operator may want to also prewire the coronary artery even after balloon-assisted BASILICA should coronary obstruction occur, in order to bail out snorkel stent [6].

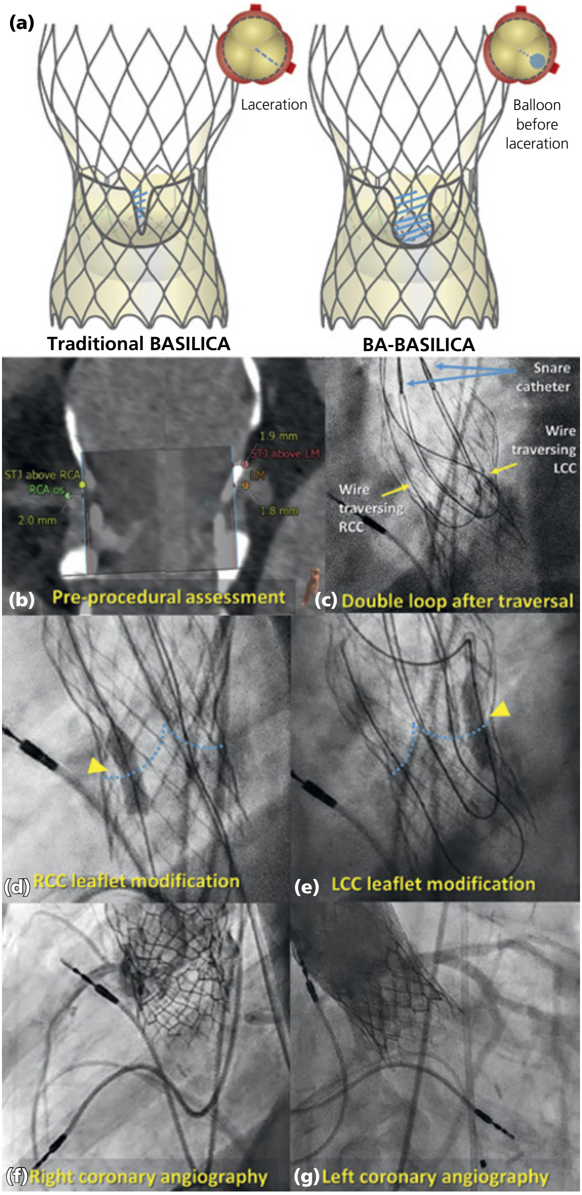
(a)
Laceration
Balloon before laceration
Traditional BASILICA
BA-BASILICA
1.9 mm
STJ above LM
LM
STJ above RCA
RCA os
2.0 mm
1.8 mm
(b) Pre-procedural assessment
Snare catheter
Wire traversing LCC
Wire traversing RCC
(c) Double loop after traversal
(d) RCC leaflet modification
(e) LCC leaflet modification
(f) Right coronary angiography
(g) Left coronary angiography

Figure 27.8 The concept of BA-BASILICA and a representative case: (a) Concept of balloon-assisted BASILICA (bioprosthetic aortic scallop intentional laceration to prevent coronary artery obstruction); traditional BASILICA (left) may not achieve adequate splay because of restriction from the outer frame of a transcatheter aortic valve (TAV), and balloon-assisted BASILICA (right) may facilitate larger splay. (b) Pre-procedural analysis showing threatened coronary arteries. (c) Two wire loops after traversal of both right coronary cusp (RCC) and left coronary cusp (LCC) leaflets. (d, e) Right and left leaflet modification with a 5-mm balloon prior to laceration. (f, g) Coronary angiography after TAV-in-TAV with no coronary flow limitation. (b-g) Source: Greenbaum et. al. [6] / with permission of Elsevier.

UNICORN

This more recently developed variant builds on the techniques described in the sections above and has only been used in valve-in-valve and native procedures. It involves identical leaflet traversal with an Astato wire and mother–daughter system; however, instead of snaring and making a "flying V" to lacerate the leaflet with electrosurgery, an 0.035" wire is delivered through a traversal microcatheter, and then the leaflet is dilated with a 12–14 mm balloon to allow for delivery of a balloon-expandable TAVR valve through the leaflet. The balloon-expandable valve is then deployed within the leaflet (presuming it is not completely lacerated with the balloon) [7]. This technique has also been described with the use of self-expanding valves; however, the balloon dilation of the leaflet may be performed with a larger balloon-aortic valvuloplasty (BAV) balloon to intentionally lacerate the leaflet, followed by deployment of the self-expanding valve.

INTENTIONAL LACERATION OF THE ANTERIOR MITRAL LEAFLET TO PREVENT LEFT VENTRICULAR OUTFLOW OBSTRUCTION (LAMPOON)

Transcatheter mitral valve replacement (TMVR) is FDA approved for "valve-in-valve" for treatment of bioprosthetic mitral valve dysfunction or "valve-in-ring" for treatment of failed valve repair with a ring. Mitral valve in mitral annular calcification ("valve-in-MAC"), while currently still "off-label," has also been performed successfully. Numerous TMVR trials are presently enrolling, and all of these procedures share a common limitation of the potential for LVOT, wherein the native LVOT area is reduced due to the permanent displacement of the anterior mitral leaflet on the outside of the TMVR valve toward the LVOT. Intentional LAMPOON, the predicate to BASILICA, was created as a way to mitigate this LVOT obstruction by lacerating the anterior leaflet at the A2 scallop [8].

RETROGRADE LAMPOON

The original technique for LAMPOON, validated with a dedicated IDE trial, involved lacerating the anterior leaflet at A2 from the femoral artery [8]. A JL guide was delivered across the aortic valve and positioned immediately underneath the anterior mitral leaflet (ventricular side), while a second guide was positioned across the mitral valve orifice, allowing a multi-looped snare to sit in the left atrium to capture the traversal wire from the guide under A2. Developed prior to BASILICA, the technique is quite similar, using a mother-in-daughter system with an Astato XS 20 inside a 0.035" Piggyback wire converter or 0.014" microcatheter. The back end of the wire is denuded and connected to an electrosurgical pencil, and 50 W of "cut mode" current is delivered to the wire tip due to insulation from the piggyback/microcatheter. As the current is delivered, the wire is advanced across the A2 leaflet into the LA and then snared and pulled into the guide that is across the mitral orifice. The piggyback/microcatheter is pulled back to the proximal end of the wire, the "flying V" is formed, and the piggyback is locked to help mark the "flying V." The wire is then advanced by pulling on the snare while advancing the wire from the traversal guide. Once the "flying V" is straddled across the A2 leaflet, then both guides are flushed with D5W, and then both guides/wires are pulled simultaneously with 70 W of "cut mode" energy lacerating the leaflet (Figure 27.9). The TMVR is then performed. In our experience, the patient is typically hemodynamically stable despite the increased mitral regurgitation, though an IABP may be used if necessary.

ANTEGRADE LAMPOON

The antegrade variant of LAMPOON was developed to make visualization of the laceration by TEE easier by mimicking the 3D surgeon's view of the mitral valve familiar to transcatheter edge-to-edge repair (TEER) operators. Rather than an arterial procedure through the aortic valve to lacerate A2, there are two steerable guides delivered to the left atrium via transseptal approach from the

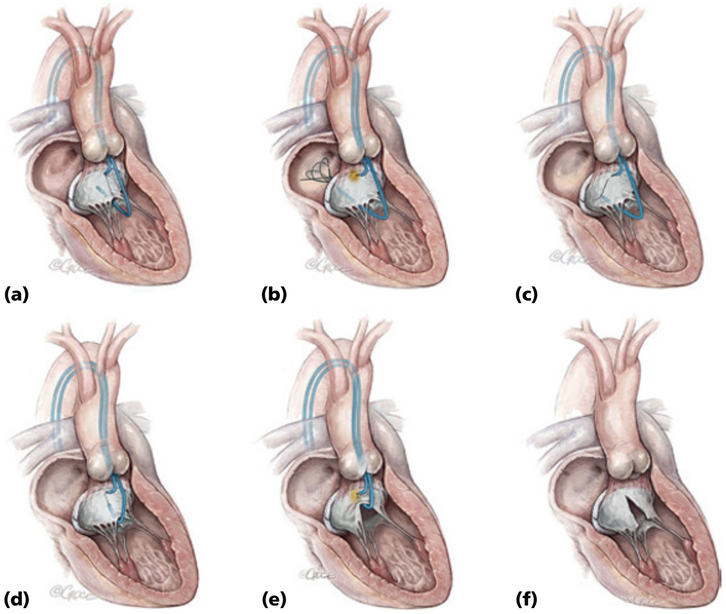

Figure 27.9 Retrograde LAMPOON [11].

femoral veins. The traversal catheter is positioned over the base of A2 while the other steerable sheath is positioned over the mitral valve orifice. A balloon-tipped wedge catheter is passed through the orifice and through the aortic valve to help ensure the snare will be free of cords. A 0.014" wire is passed through the wedge catheter in the aorta and snared with a gooseneck snare to serve as a rail to improve stability of the snare in the LVOT. A JL3.5 guide is advanced over the rail into the LV. A three-loop Atrieve snare (Angiotech, Gainesville, FL, USA) is delivered through the JL guide sitting below the A2 scallop of the mitral valve. The typical mother-daughter system of Astato XS 20 inside a microcatheter/piggyback wire converter inside a 6F J4 guide is delivered through the steerable guide (e.g. Agilis) over the base of A2. The Astato XS 20 is advanced through the base of A2 while the denuded back end of the wire is connected to an electrosurgical pencil, and 50 watts of "pure cut" energy is delivered. The wire is then snared and pulled into the JL4 guide in the LV, and the "flying V" is formed and positioned at the anterior mitral valve leaflet. The two guide catheters are injected with D5W while the guides are pulled superiorly, and the "flying V" lacerates with 70 watts of "pure cut energy" (Figure 27.10). The cut is confirmed on TEE.

TIP-TO-BASE LAMPOON

In cases where there is a surgical mitral valve leaflet that may cause LVOT obstruction, the procedure can be simplified by taking advantage of the surgical frame as a backstop for pulling the "flying V." This variant does not require leaflet traversal, so there is a single transseptal steerable sheath that delivers a wedge across the mitral and aortic valves, and ultimately an Astato XS 20 is sent through the wedge and snared by a JR4 guide and gooseneck snare. The "flying V" is again formed and advanced to the leaflet in the LVOT, and the leaflet is cut by pulling on the two guides with 70 watts of "pure cut energy" using the surgical suture ring as a backstop to prevent lacerating the aortic valve or aortomitral curtain. The other advantage of this technique is that the procedure can easily be repeated if an inadequate split is obtained. If performing tip-to-base LAMPOON with a mitral ring, then care must be taken to ensure the LA steerable guide stays at A2 when pulled to make the appropriate split along the LVOT (Figure 27.11) [9,10].

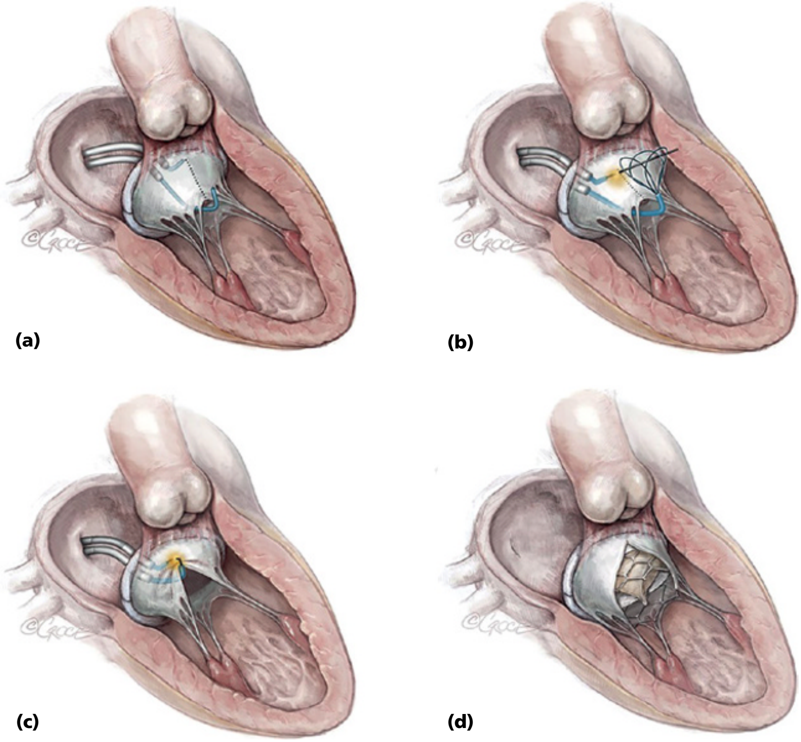

Figure 27.10 Antegrade LAMPOON. Source: Case et al. [11] / with permission of AME Publishing Company.

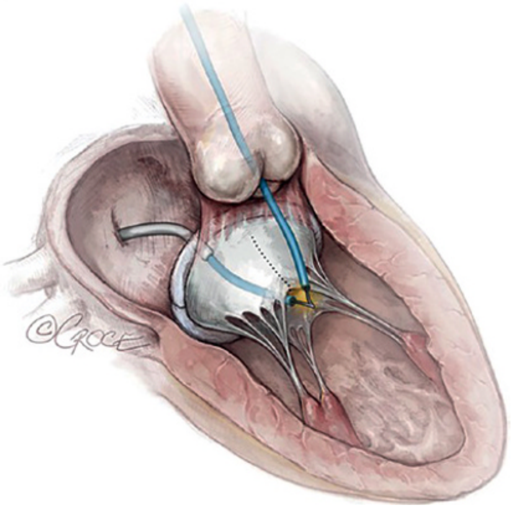

Figure 27.11 Tip to base LAMPOON. Source: Case et al. [11] / with permission of AME Publishing Company.

BALLOON-ASSISTED LAMPOON

If the predicted neo-LVOT is really concerning, there may be a need for a larger penumbra of effect with the traversal. Once the traversal wire is crossed and snared, then a coronary angioplasty balloon 4.0 mm in diameter can be used to dilate the leaflet traversal prior to splitting with the “flying V” [11].

SEPTAL SCORING ALONG MIDLINE ENDOCARDIUM (SESAME)

The most recent iteration of the electrosurgical principles is the septal scoring along midline endocardium (SESAME) procedure [12,13]. This procedure was developed as an alternative to surgical myotomy/myectomy and alcohol septal ablation. Surgical procedures obviously have their own inherent risk and are not performed on high-risk patients. Alcohol septal ablation is limited by available septal perforators, high risk of heart block requiring a pacemaker, frequent inadequate improvements in LVOT obstruction, and risk of iatrogenic ventricular septal defect (VSD). The SESAME procedure mimics the original Morrow septal myotomy, which essentially made a single cut along the midline of the septal knuckle, allowing the muscle to splay and relieve LVOT obstruction [14]. Modern surgical techniques involve a more extensive resection of muscle from the LVOT.

Tips and Tricks

The SESAME procedure again uses the Astato XS 20 or 40 stiff 0.014″ wire delivered through a 6F guide pointed across the aortic valve between the nadir of the RCC and LCC to center on the LVOT and avoid the membranous septum [12,15]. An 8F deflectable guide is advanced to the ascending aorta to help steer and stabilize a 7F Champs guide (Medtronic, Minneapolis, MN, USA) across the aortic valve to engage the LV endocardial septum. An Astato XS 40 0.014″ wire is nested inside a Corsair XS 0.014″ microcatheter (Asahi Intecc, Irvine, CA, USA) and is then embedded into the septal knuckle. This wire is then carefully steered through the endocardium using CT-prescribed trajectories trans-thoracic echocardiography (TTE) and trans-esophageal echocardiography (TEE) to stay midline within the septal knuckle and avoid penetrating too close to the RV. Using a small bend at the tip of the wire, one can steer through the myocardium and eventually exit the septal knuckle at the pre-planned depth. Once the wire re-enters the LV cavity, a 6F JR guide is then advanced to the LV, through which a 30 mm Atrieve snare (Angiotech, Gainesville, FL, USA) is used to capture the Astato wire. The 0.014″ microcatheter is then removed from the traversal wire and replaced with a FineCross inside a Navicross (0.035″ microcatheter), which are advanced to the exit point after the “flying V” is made on the Astato. The back end of the Corsair is cut to size and advanced over the snaring guide (JR4) to add insulation to that side of the wire as well, with the “flying J” positioned at the tips of the Piggyback and Corsair. Under 50 W and infusion of NS, the Astato is electrified, and the guides are carefully pulled, lacerating the septum (Figure 27.12).

The benefits of SESAME over alcohol septal ablation include a more precise cut, lack of need for an appropriate septal perforator, and low risk of complete heart block. This procedure remains in its infancy, and techniques are being rapidly improved and dedicated devices being developed to help control the laceration and minimize the risk of VSD or free wall rupture.

MISCELLANEOUS

ELASTA-CLIP

There are few options for non-surgical patients who have had TEER with inadequate results secondary to either marked residual mitral regurgitation or severe mitral stenosis. TMVR may be a solution, but the TEER device makes this prohibitive. One option is to liberate the

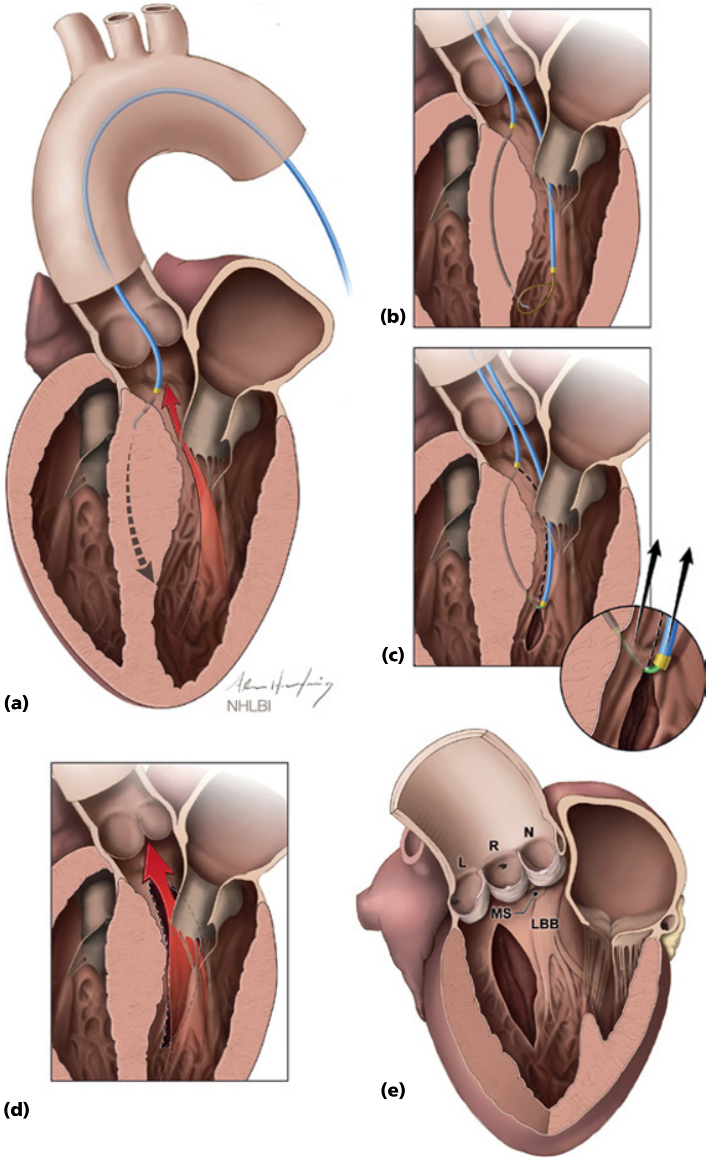

Figure 27.12 Septal scoring along the midline endocardium (SESAME) procedure. (a) A stiff angioplasty guidewire with a chronic total occlusion tip is navigated through the interventricular septum. (b) The guidewire completes the intramyocardial trajectory, with microcatheter support, and reenters the left ventricle cavity into a snare. (c) A modified flying V lacerating surface is created, and traction is applied during electrification to create the myotomy. (d) Following transcatheter SESAME, the muscle splays, increasing space in the left ventricular outflow tract, with increased blood flow. (e) The SESAME laceration avoids the conduction system. L, left cusp; LBB, left bundle branch; MS, membranous septum; N, noncoronary cusp; and R, right cusp [15].

TEER device from the anterior leaflet with the ELASTA-CLIP procedure. Similar to the LAMPOON setup, there are two steerable sheaths delivered to the left atrium, and instead of penetrating the anterior leaflet like in antegrade LAMPOON, the wire is delivered through either the medial or lateral orifice, and then a snare is passed through the opposite orifice, and the wire is externalized to make the "flying V." Using the steerable sheaths, the wire is kept anterior to the TEER device, and the anterior leaflet is lacerated with 70 W on cut mode. Then TMVR is performed with the TEER device only attached to the posterior leaflet and out of the LVOT [16].

Recanalizing subclavian vein We have used the insulated mother-in-daughter technique to traverse occluded subclavian veins for pacemaker upgrades. The wire is steered to follow the existing pacemaker lead, as confirmed in two projections [17].

ABBREVIATIONS

TAVR	Transcatheter aortic valve replacement
BASILICA	Bioprosthetic or native aortic scallop intentional laceration to prevent iatrogenic coronary artery obstruction during TAVR
LAMPOON	Intentional laceration of the anterior mitral leaflet to prevent left ventricular outflow obstruction
TMVR	Transcatheter mitral valve replacement
IDE	Investigational device exemption
CT	Computed tomography
IM	Internal mammary
RDC	Renal double curve
F	French
AL	Amplatz left
JR	Judkins right
LV	Left ventricle
UNICORN	Undermining Iatrogenic Coronary Obstruction With Radiofrequency Needle
BATMAN	Balloon assisted translocation of the mitral anterior leaflet to prevent left ventricular outflow obstruction
SESAME	Septal Scoring Along Midline Endocardium
ELASTA-Clip	Electrosurgical laceration and stabilization of MitraClips

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CHAPTER 28

Septal Puncture and Inoue-balloon Mitral Valvuloplasty

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*Basic; **Advanced; ***Rare, exotic, or investigational

$, <100.00 $US extra; $$, >100.00 $US extra

⌛, <10 min extra; ⌛⌛, >10 min extra

💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

Percutaneous balloon mitral valvuloplasty (BMV), introduced in 1984 by Inoue et al. [1], has ushered in a new dimension in the treatment of patients with mitral stenosis. Extensive clinical studies have established that this minimally invasive, nonsurgical procedure is a safe and effective therapeutic modality in selected patients with mitral stenosis [2] and is equivalent to or even better than surgical commissurotomy [3].

With successful balloon valve enlargement, there is generally a twofold increase in the mitral valve area [4] and an associated dramatic fall in transmitral valve gradient, left atrial pressure, and pulmonary artery pressure. These hemodynamic benefits are mirrored in postprocedural improvement in the patient's symptoms and exercise tolerance [5]. The long-term results of BMV are excellent, especially when the acute results are optimal and in the presence of good valve morphology [5].

Besides the original Inoue technique using size-adjustable, self-positioning balloon catheters, various other techniques using fixed-size balloon catheters have been developed for performing BMV. These include the antegrade (transvenous) approaches with one or two balloon catheters through one or two interatrial septal punctures [6, 7] and the retrograde (transarterial) approaches with or without transseptal access [8]. However, the Inoue-balloon catheter system via the transvenous approach has remained the principal BMV technique used today.

The present chapter focuses on discussion of the pitfalls and tricks in Inoue-balloon BMV to ensure success and to minimize complications of the procedure. The instrumentation of the Inoue-balloon catheter system has been extensively described previously [1, 3] and thus is omitted in this chapter.

TRANSSEPTAL ACCESS

Transseptal catheterization is a vital component of BMV. Transseptal puncture must not only be executed safely to avoid cardiac perforation but also be made at an appropriate septal site to facilitate balloon crossing of the stenosed mitral valve. Inoue-balloon percutaneous transvenous mitral valvuloplasty is conventionally performed through the right femoral vein. Alternative approach routes, however, have been described in the past. Joseph et al. [9] used right jugular vein access.

To avoid cardiac perforation during transseptal catheterization, some operators have resorted to routine intraprocedural transesophageal echocardiography; however, even with echocardiographic guidance, cardiac perforation may still occur [10]. Therefore, acquisition of basic transseptal puncture skill is essential. To perform the transseptal procedure, biplane fluoroscopic equipment is preferable, but single-plane fluoroscopy is usually sufficient for the experienced. Intracardiac echocardiography is useful in guiding transseptal catheterization in BMV [11], but its utilization adds to the procedure cost.

Instruments for Septal Puncture

The essential instruments include (1) a Brockenbrough™ needle, (2) a 7- or 8-Fr dilator catheter, and (3) an outer Mullins sheath. The use of the sheath is optional, but its use is recommended, especially for inexperienced operators, for two reasons: to prevent inadvertent perforation of the dilator by the needle during its insertion and to prevent left atrial perforation during insertion of the catheter/needle into the left atrium because the sheath tip works as a safety stopper at the septum.

Catheter/needle Fitting Exercise

A catheter/needle fitting should be performed before its insertion into the patient. First, fully insert the transseptal needle until its tip extends beyond the catheter (Figure 28.1a). Then, withdraw the needle until its tip is concealed slightly (2–3 mm) within the tip of the catheter. The operator should fix his or her right index finger on the needle between the direction

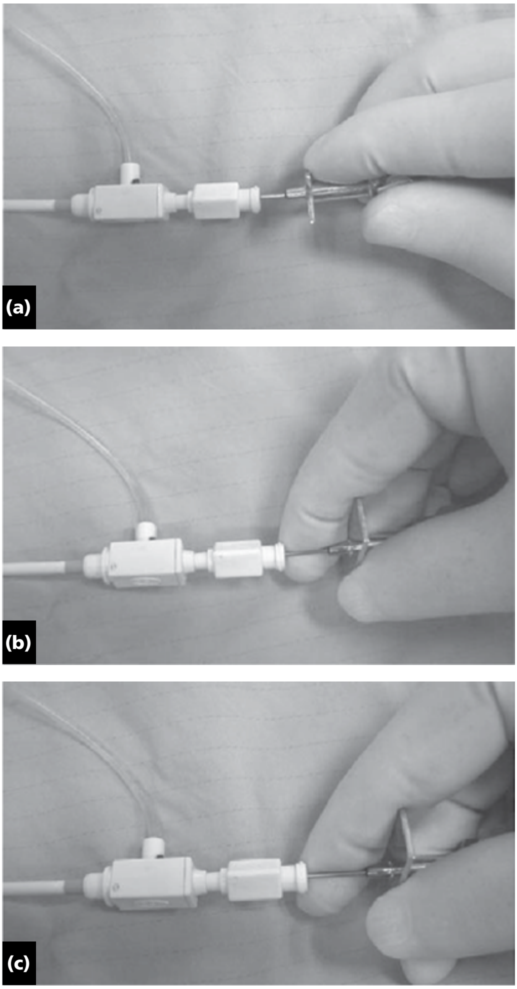


Figure 28.1 Catheter/needle fitting exercise. (a) First, fully insert the transseptal needle until its tip extends beyond the dilator tip. (b) The needle is then withdrawn until its tip is aligned with the dilator tip. (c) It is pulled back farther so that the needle tip is concealed slightly (2–3 mm) from the dilator tip. The index finger is fixed as a stopper on the needle between the direction indicator and the catheter hub to prevent the needle from moving forward and protruding from the dilator tip. This is of vital importance during in vivo manipulation of the catheter/needle. The depth and the angle of the stopper finger (c) are adjusted according to the distance between the direction indicator and the catheter hub in each catheter/needle set. Each side of the direction indicator is held by the thumb and the index finger, respectively. This makes rotation of the indicator easier and also allows the blunt part of the direction indicator to be visible to the operator and the tutor, if any. Courtesy of www.ptmv.org

indicator and the catheter hub (Figure 28.1b) to prevent the needle from accidentally moving forward and protruding from the catheter tip. This is of vital importance during in vivo manipulation of the catheter/needle. The direction indicator on the needle is held between the thumb and the index finger (Figure 28.1c).

Landmarks for Optimal Puncture Site

To select an optimal transseptal puncture site, there are two imaginary reference lines that need to be defined first: (1) the vertical "midline" and (2) the horizontal "M-line." The target site for septal puncture is, as a rule, located at the intersecting point of the vertical "midline" and the horizontal "M-line."

Definition of the vertical "midline"

1. **Inoue's angiographic method.** Inoue has devised a specific transseptal puncture technique designed for Inoue-balloon BMV, incorporating the concept of a vertical "midline," a line assumed to divide the interatrial septum into anterior and posterior halves [12]. This line is defined based on the landmarks obtained from right atrial angiography during normal respiration in the frontal plane (Figure 28.2a,b).
2. **Hung's modified method.** Making use of the fact that in most cases of mitral stenosis the left atrial silhouette is visible under fluoroscopy, one of the authors (JSH) has modified Inoue's method of defining the "midline." In this method, the aortic valve instead of the tricuspid valve is used as a landmark because of their proximity. Therefore, point T is substituted with the tip of a pigtail catheter (Figure 28.2c, point A) touching the aortic valve (usually the noncoronary sinus of Valsalva) in the frontal view. A horizontal line is drawn from point A to L, where the line intersects the right lateral edge of the left atrium. The "midline" thus derived is usually identical to that from Inoue's angiographic method.

Tips and Tricks

****Variances of the "midline"** The septum lies within the superimposed area between the two atria, and therefore there is no septum outside this area. The lateral (or posterior) limit of the septum is the lateral border of the medial atrium, usually the left atrium. Infrequently (such as in patients with giant left atria), the lateral border of the right atrium is medial to that of the left atrium, and thus point L should be on the right atrial border because there is no septum laterally beyond this point.

*****Transseptal puncture in semi-recumbent position** BMV can be performed with the patient in a semi-recumbent position, such as when the patient is unable to assume a supine position because of severe pulmonary edema and needs to undergo BMV urgently. In this setting, the "midline" can be defined in the frontal view with appropriate caudal tilting [13]. The frontal image intensifier needs to be tilted in a caudal angle corresponding to the degree of semi-recumbency to negate the patient's tilt and "normalize" the positional relationship of the various intrathoracic structures. For example, if the patient is lying at 30° to the horizontal, the frontal image intensifier should be rotated to 30° caudally.

Definition of the horizontal "M-line" The "M-line" is a horizontal line crossing the center of the mitral annulus (point M) as visualized in a left ventriculographic diastolic stop-frame obtained in the 30° right anterior oblique (RAO) projection (Figure 28.3a). This line is memorized in relation to the vertebral body; there is no need to plot it on the image monitor screen. The stop-frame angiogram is also used as a roadmap during transseptal puncture and balloon catheter manipulation (Figure 28.3 b,c).

In individual cases, the puncture point in relation to this line may have to be adjusted. For example, in patients with a more vertically oriented left ventricle, the puncture site is chosen

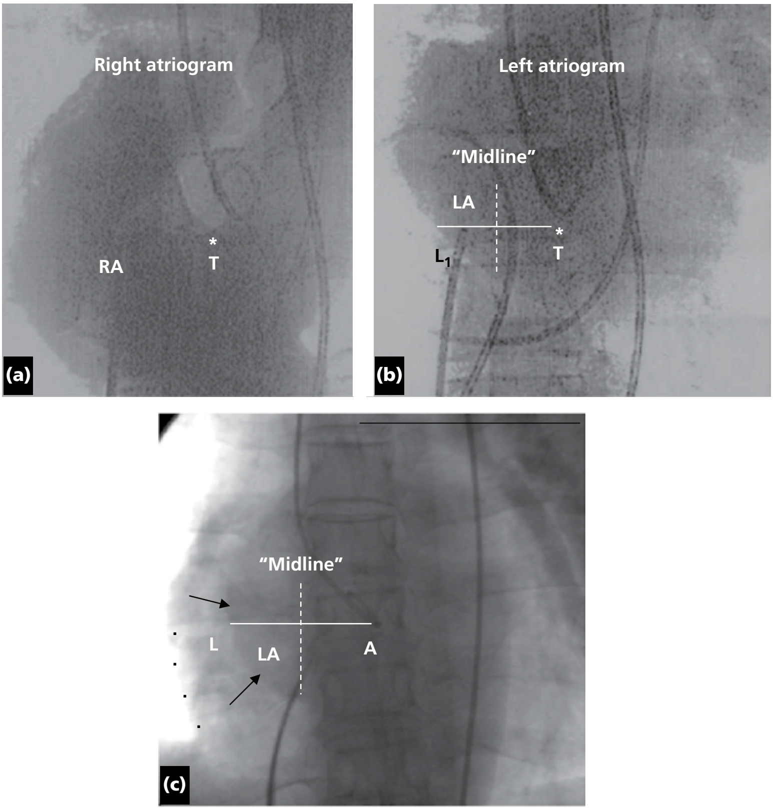


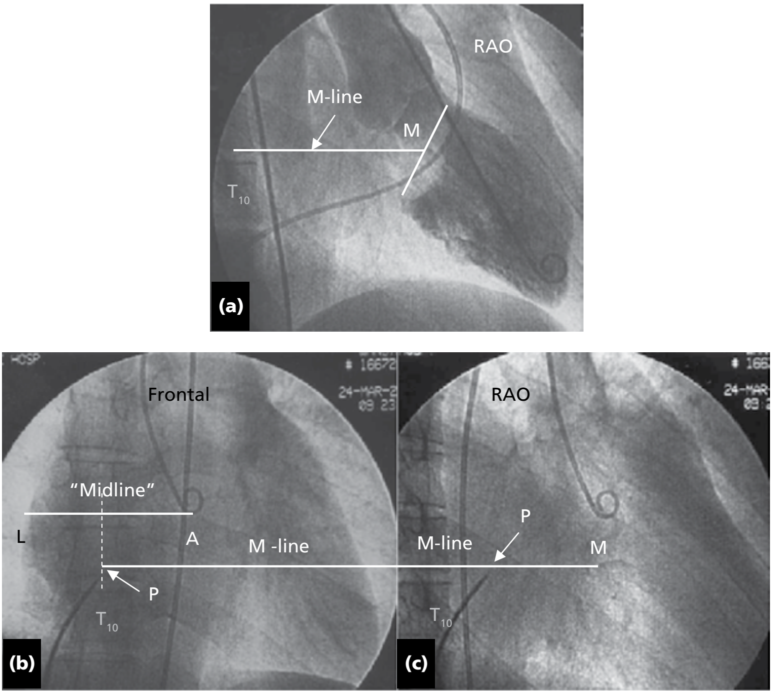
Figure 28.2 The "midline": angiographic method (a,b). The upper end of the tricuspid valve at systole (point T, marked with an asterisk) is determined on a stop-frame frontal right atrial (RA) angiographic image (a) and translated to a stop-frame left atrial (LA) image (b). On (b), an imaginary horizontal line is drawn from point T to point L, where the line intersects the lateral border of the atrium encountered first (usually the LA, as in this case). Point L is assumed to be the posterior limit of the septum. The dotted vertical line crossing at the midpoint between T and L is the "midline." (c) Fluoroscopic method: a horizontal line is drawn from the tip of the pigtail catheter (point A) to L, the LA silhouette (black arrows), to define the "midline." The dotted line indicates the right atrial silhouette. Courtesy of www.ptmv.org

slightly above the horizontal "M-line." In patients with giant left atria, the operator is often forced to make septal puncture more caudal to the "M-line."

Tips and Tricks

Differences between inoue's and hung's landmarks For septal puncture, Inoue's landmark uses contrast to differentiate the location of the left and right atrium, while Hung's landmark uses fluoroscopy to highlight a lighter left atrium silhouette (Figure 28.4).

****Appropriateness of the inoue method – giant left atrium, severe kyphoscoliosis** Inoue's angiographic method is suitable in the following situations: (1) for operators inexperienced with the transseptal puncture technique; (2) in cases in which atrial silhouettes are not well visualized under fluoroscopy; and (3) in extremely difficult cases of transseptal


RAO
M-line
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T_{10}
(a)
Frontal
"Midline"
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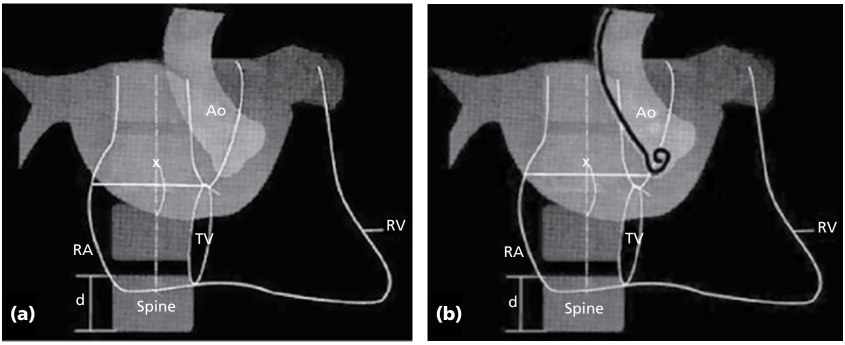
P
T_{10}
(b)
RAO
P
M-line
M
T_{10}
(c)

Figure 28.3 Defining the horizontal M-line, vertical "midline," and target puncture site. (a) The M-line is obtained using the stop-frame RAO view left ventriculogram. This line is memorized in relation to the vertebral body of T10 and transcribed in the (b) frontal and (c) RAO views. The vertical "midline" is defined in fluoroscopic frontal view. The target site for septal puncture (point P) is located at the intersecting point of the vertical "midline" and the horizontal M-line (b). A = pigtail catheter tip; RAO = right anterior oblique; T_{10} = 10th thoracic vertebra. Courtesy of www.ptmv.org


Ao
x
RV
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RA
d
Spine
(a)
Ao
x
RV
TV
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d
Spine
(b)

Figure 28.4 (a) Inoue's landmark uses contrast to show the difference between the left and right atrium. (b) Hung's landmark uses fluoroscopy to highlight a clear left atrium. Ao = aorta; d = distance; RA = right atrium; RV = right ventricle; TV = tricuspid valve. Courtesy of Dr. JS Hung, Taipei, Taiwan.

puncture, e.g. in the presence of a giant left atrium [12] or severe kyphoscoliosis [14]. In these cases, it may be necessary to perform biplane (frontal and lateral) right angiography to properly visualize the atrial septal orientation and relative anatomic relationships of both atria, the tricuspid valve, and the aorta.

SEPTAL PUNCTURE

Placement of Transseptal Catheter/Needle

The catheter/sheath is inserted via the right femoral vein over a guidewire into the superior vena cava to the level of the carina. The catheter is aspirated and flushed after removal of the wire. Then, the Brockenbrough needle, attached with a 5-mL plastic syringe containing pure contrast medium, is inserted into the catheter and carefully advanced under fluoroscopic view until its tip reaches the predetermined position (refer to "Catheter/needle Fitting Exercise"). The needle is allowed to rotate freely during its passage. The right-hand stopper finger is now firmly kept between the catheter hub and the direction indicator of the needle to prevent the needle from moving forward (Figure 28.1). Extreme care should be taken not to let the needle slip forward during subsequent manipulation of the catheter/needle.

Catheter/Needle Manipulation

Under frontal fluoroscopic view, the needle-fitted transseptal catheter with its direction indicator pointing at about 4 o'clock is slowly withdrawn downward (caudally) from the superior vena cava. A clockwise rotation is applied to the direction indicator to align the catheter/needle on the "midline." The catheter/needle is further withdrawn until its tip reaches the level of the pigtail tip touching the aortic valve (Figure 28.5 a,b).

Under lateral view, the catheter/needle is further withdrawn caudally while contrast medium is being injected (septal flush method) [12] by an assistant or using the operator's right hand while fixing the catheter hub and the direction indicator using the left hand to outline the right atrial margin of the septum (Figure 28.5 c,d). The catheter tip is finally set at the curvilinear portion of the septum at the altitude of the "M-line" (Figure 28.5e).

Subsequently, the catheter needle/needle tip position is viewed under 30° RAO projection, contrasted with the left ventriculogram roadmap, to confirm the optimal septal puncture site as well as to avoid puncture of other structures (Figure 28.5d). The catheter/needle tip is now seen on the "'M-line," usually just anterior to the vertebra and away from the ascending aorta, the coronary sinus, and the tricuspid valve. Although frontal and lateral views are sufficient for experienced operators, the RAO view is especially vital for inexperienced operators.

Tips and Tricks

****Exact positioning of the catheter/needle tip** In most cases of mitral stenosis, a sudden sharp movement of the catheter/needle toward the left is not observed when the tip of the transseptal assembly falls over the limbic ledge and enters the fossa ovalis. This is because the atrial septum bulges markedly toward the right atrium, making the fossa ovalis shallower. When the septal bulge begins in the upper septum, the catheter/needle being withdrawn from the superior vena cava takes a lateral course to the "mid-line." In this case, turning the needle to the 3 o'clock direction may lead the catheter/needle to a medial position. If not, the needle alone can be withdrawn slightly, and the floppy tip of the catheter should tend to flip medially. Then the needle is advanced slowly and carefully to bring its tip back to the original position while keeping the catheter tip in the medial position. If these manipulations also fail to place the catheter/needle medially, the latter is withdrawn further downward and close to the lower edge of the left atrium (passing the caudal end of the bulge). With the needle pointing toward the left (about 3 o'clock), the catheter tip is allowed to shift medial to the "midline" and then carefully advanced cephalad. A clockwise twist is made to the needle, and the catheter tip is steered to, or near, the target point.

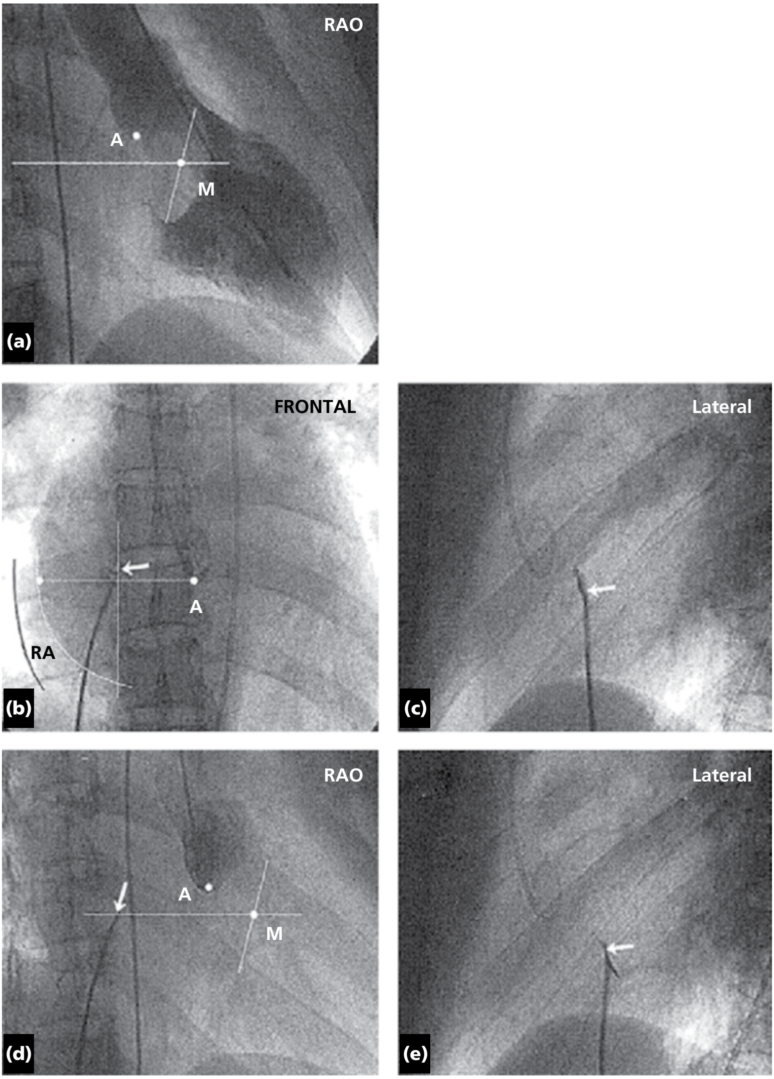


Figure 28.5 Catheter/needle manipulation. (a) Stop-frame left ventriculogram in 30° right anterior oblique (RAO) view shows a horizontal line, the M-line, crossing the center of the mitral annulus. (b) Under frontal fluoroscopic view, the needle-fitted transseptal catheter is slowly withdrawn downward (caudally) from the superior vena cava to align the catheter/needle on the vertical midline. The catheter/needle is further withdrawn until its tip reaches the level of the pigtail tip touching the aortic valve (point A). (c) Under lateral view, the catheter/needle is further withdrawn caudally while contrast medium is being injected (septal flush method) to outline the right atrial margin of the septum. (d) The catheter/needle is further withdrawn to set its tip at the curvilinear portion of the septum at the altitude of the M-line. At this point, the catheter/needle is observed to be pointed dorsally. (e) Subsequently, the catheter/needle tip position is viewed under 30° RAO projection and contrasted with the left ventriculogram roadmap (a) to confirm the optimal septal puncture site as well as to avoid puncture of other structures (the aorta, the coronary sinus, and the tricuspid valve). The catheter/needle tip is now seen on the M-line, usually just anterior to the vertebra. RA = right atrium.

****Exact positioning of the catheter/needle tip in giant left atrium** If the atrial septum bulges markedly toward the right atrium, especially in cases of a giant left atrium, it is difficult to align the catheter tip with the "midline" and perpendicular to the septum. The catheter tip faces strong resistance at 4 o'clock when it touches the bulged septal surface. As the needle is being rotated clockwise, the catheter/needle will give way suddenly. In effect, the needle tip flips over the crest of the bulge and points toward the right side of the patient at 9 o'clock. To prevent this, the catheter should be pressed slightly against the septum as the needle is being rotated clockwise to 6 to 7 o'clock. At the same time, a slight counterclockwise twist is applied to the catheter with the left hand to counter any excessive clockwise rotation of the needle. If the crest of the bulge happens to be at the "midline," it is not possible to make a puncture on the line. In this case the puncture site is settled in the region slightly lateral to "the midline."

****Repositioning the catheter/needle tip after a failed first attempt** If the initial pass of the transseptal catheter/needle is not successful in engaging it at an appropriate puncture site, the needle is removed from the catheter, and the second attempt is begun by repositioning the catheter in the superior vena cava over a guidewire. For experienced operators, the alternative is to reposition the catheter/needle high in the right atrium. This is done by setting the needle in the 12 o'clock direction (ventrally) and carefully moving the catheter/needle upward (cephalad) while slightly rotating the direction indicator of the needle clockwise and counterclockwise to make certain the catheter tip is free in the right atrium and not caught against the right atrial appendage or its free wall. (Figure 28.6).

****Needle tip reshaping** Reshaping of the distal needle to make it more curved may be necessary in the following situations: (1) when the catheter/needle tip tends to take a more lateral course to the "midline" despite counterclockwise rotation of the direction indicator to the 3 o'clock direction; and (2) when at the intended puncture site there is a sharp angle between the direction of the catheter/needle tip and the septum, making septal penetration impossible or causing septal dissection when the needle is advanced forward.

The Technique of Septal Puncture

When the operator is satisfied with the intended puncture site, the catheter/needle is pressed firmly against the septum. Usually cardiac pulsations (the so-called septal bounce) are felt by the right hand holding the catheter/needle. While keeping the catheter firmly against the septum to prevent it from slipping away from the puncture site, the operator releases the stopper-finger and advances the needle forward. The needle is aspirated, and contrast medium is injected to confirm its entry into the left atrium. If no blood is aspirated, the needle either has dissected the high septum or is caught in the thickened septum. Staining of the septum with injection of a small amount of contrast medium (septal stain method) [12] easily distinguishes between the two (Figure 28.7). This type of septal staining is of no consequence because contrast medium is absorbed rapidly. When the high septum is dissected, it is stained in a more vertical fashion. In this situation the needle is withdrawn, and septal puncture is made at a slightly more caudal site.

Tips and Tricks

Best ways to puncture the septum In order to puncture at the correct location, the septal puncture must always be inside the left atrium silhouette. Always use the # landmark in order to avoid puncturing the right atrium, aorta, tricuspid valve, and coronary sinus (Figure 28.8a). Always manipulate the catheter and/or needle carefully and reshape the needle accordingly in difficult cases. Always confirm the left atrium entry by staining, contrast medium, pressure, or blood oximetry before advancing the sheath.

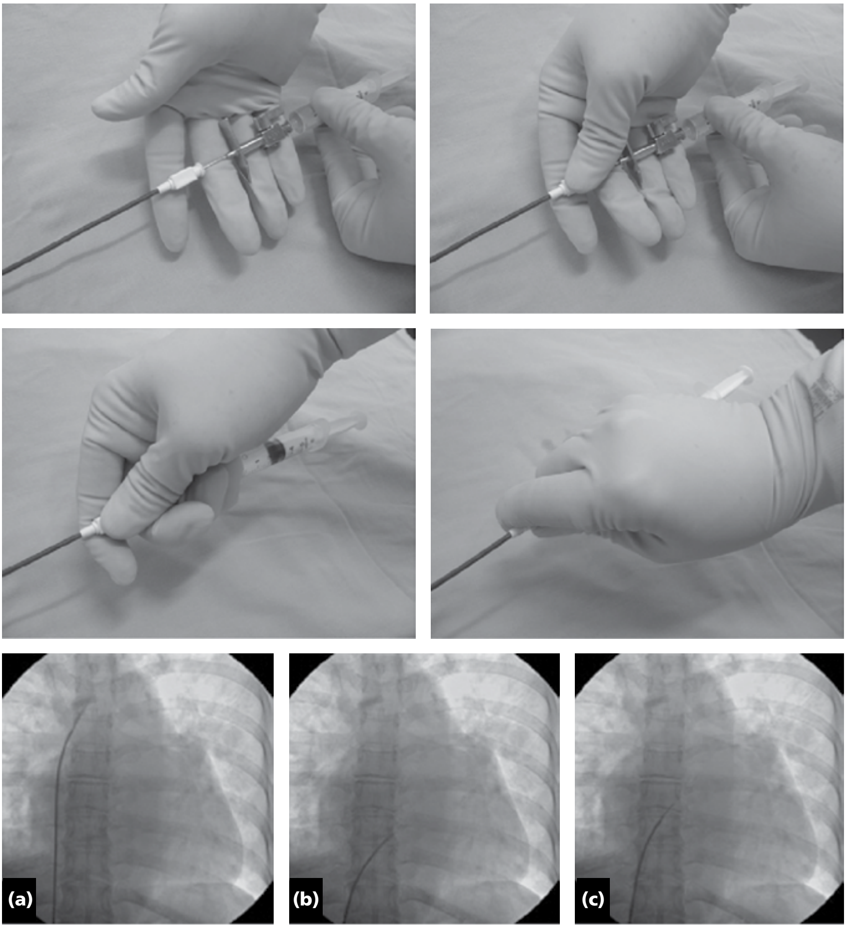


Figure 28.6 (a) Pull back the whole system (needle/catheter) from the superior vena cava, pointing at 4 to 5 o'clock. (b) When the catheter tip jumps down, turn posterior, then turn back near to the desired puncture site. (c) Push against the septum, feel the pulsation, make the puncture, and verify the position by left atrial pressure.

In summary, the art of safe and fast septal puncture is to puncture within the hash "#" landmark inside the left atrium silhouette (Figure 28.8a). The optimal transseptal puncture position for BMV is the fossa ovalis, which facilitates balloon crossing and minimizes the residual transseptal shunt (Figure 28.8b).

****How to puncture a thick septum** When the needle is caught in the thick septum (usually in the muscular septum), the stain takes a more oblique orientation (Figure 28.9). In this case the catheter/needle is carefully forced across the septum as described as follows, or the puncture is attempted at another site. When the catheter/needle is being advanced, a "tenting" of the septum is observed before the septum is entirely pierced by the catheter/needle. With pressure monitoring, it is not possible to differentiate dissection of the high septum from

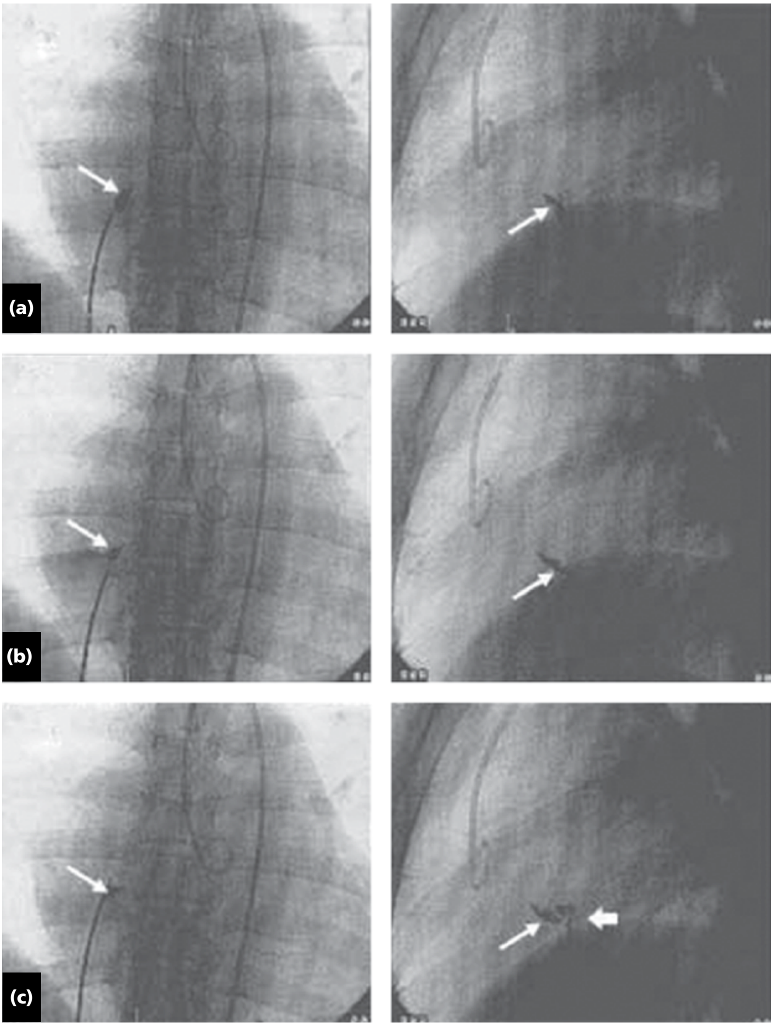


Figure 28.7 Septal stain method: staining the septum with injection of a small amount of contrast medium. Courtesy of Dr. JS Hung, Taipei, Taiwan.

entrapment of the needle in the thick septum. This is another reason why the authors perform the transseptal puncture without constant pressure monitoring.

When marked resistance is encountered during septal puncture, a sustained force is applied to the catheter/needle. After several cardiac beats, not infrequently a "give" is felt or seen under fluoroscopy when the catheter/needle finds its way into the left atrium. If this means failing to place the catheter/needle across the septum, a Bing stylet, which has a blunt tip, is inserted and extended beyond the needle. The catheter/needle is carefully forced through the tough septum by a forward push with the right hand while applying counter-resistance with the left hand. During the process, the operator must be prepared to withdraw the needle as soon as the catheter enters the left atrium so that the excessive forward momentum does not carry the needle forward and perforate the left atrial wall, causing cardiac tamponade.

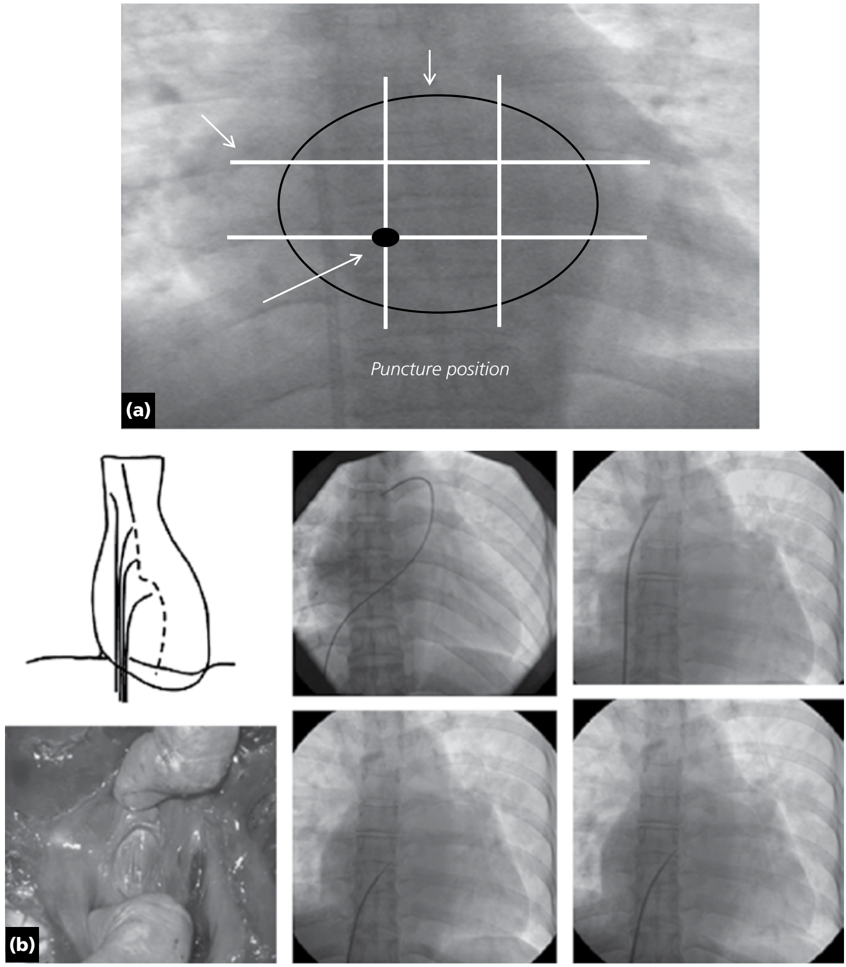


Figure 28.8 (a) The best location for puncture is within the hash "#" landmark inside the left atrium silhouette. (b) The optimal transseptal puncture position for BMC is the fossa ovalis, which facilitates balloon crossing and minimizes the residual transseptal shunt.

****How to avoid puncturing the aorta, tricuspid valve, and coronary sinus** When the catheter/needle is set on the "midline," puncture of these structures can be avoided. Being confirmed in the RAO projection, the intended puncture site is clearly separated from the aorta, the tricuspid valve, and the coronary sinus (Figure 28.9c).

****Avoid puncturing medial to the "midline"** When a puncture is made medial to the line, there is a risk of puncturing the aorta, tricuspid valve, or coronary sinus. More importantly, the puncture site thus made is too close to the mitral valve, and this makes balloon crossing of the mitral valve difficult or even impossible unless the posterior-loop method (refer to "Crossing the Mitral Valve") is employed. Slight lateral deviation of the puncture site to the "midline" is permissible, especially in patients with relatively small left atria.

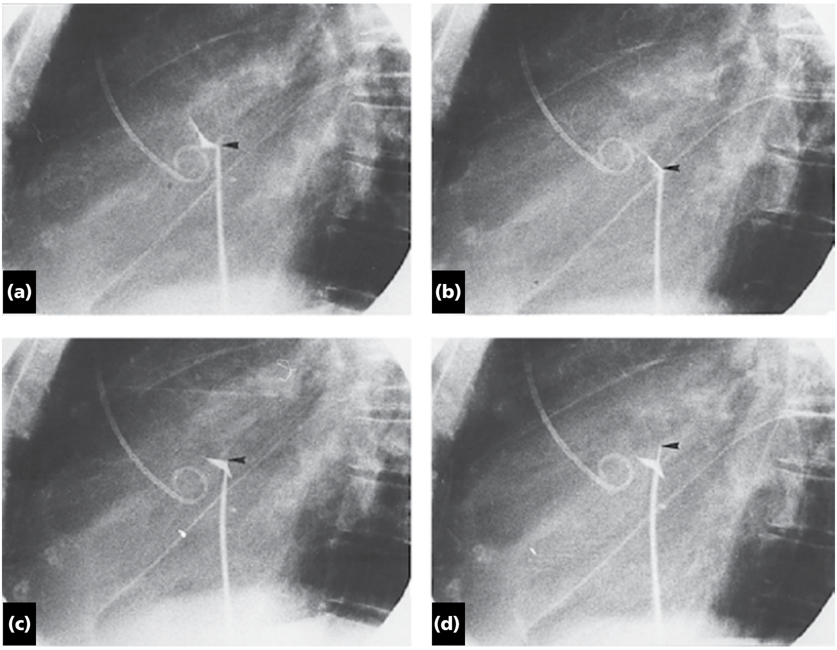


Figure 28.9 Septal flush/stain method illustrated in lateral views. (a) As the catheter/needle assembly is withdrawn caudally, it is flushed with contrast medium, which outlines the right atrial margin of the septum. The tip of the catheter/needle (black arrow) is at the high anterior septum. (b) The catheter/needle is withdrawn to set its tip at the puncture target site, and the needle is advanced. (c) As the puncture is made in the thickened muscular septum, the needle is caught in the septum as demonstrated by the oblique septal stain. When the catheter/needle is advanced, a "tenting" of the septum is observed. (d) The needle is carefully forced through the septum. Source: Reproduced with permission from [11] / Elsevier.

*****Inadvertent puncture of the aorta** This rare event, confirmed by contrast injection or pressure recording, is usually uneventful if the needle is withdrawn immediately; however, should the operator unknowingly advance the catheter into the aorta, it should not be withdrawn. The patient should be sent for emergency surgery with the catheter left in the aorta.

****How to avoid puncturing the right atrium** To avoid injury to the right atrium, the catheter/needle should be carefully manipulated, and the needle tip always kept inside the catheter tip. When right atrial perforation is detected by contrast opacification of the pericardial space, do not advance the catheter, and withdraw the needle/catheter immediately. Usually cardiac tamponade does not ensue, and the operator may proceed with a puncture attempt at the optimal site. It is important to note that there may not be a septum in an area near the inferior (caudal) border of the left atrium caudal to the "M-line" because the atrium often bulges caudally beyond the true septal boundary. This is especially true in patients with a large left atrium. If this region is punctured, the catheter/needle may perforate the right atrial wall and then enter the left atrium (the so-called "stitching" phenomenon) [12]. After the guidewire is placed in the left atrium and the catheter is withdrawn, cardiac tamponade ensues. To avoid puncturing the right atrium, the setting of the catheter/needle tip at the septum can be confirmed by (1) observing the "septal bounce," and (2) the septal flush/stain method, as discussed previously (Figures 28.5–28.7).

Confirmation of Left Atrial Entry

After entry of the needle in the left atrium is confirmed, first by contrast medium injection followed by pressure recording, the needle direction is set toward 3 o'clock (left side of the patient). If there is no or little resistance, the catheter/needle is advanced forward about 2 cm into the left atrium. Then, the catheter alone is advanced another 2 cm (or until the tip of the sheath meets resistance at the septum) while the needle is being withdrawn.

Heparinization

Upon removing the needle after the catheter is placed in the left atrium, heparin, 100 U/kg body weight, should be given immediately through the catheter. After baseline hemodynamic studies, BMV is performed. If the patient has been on warfarin before BMV, the drug is discontinued 2–3 days before the procedure and substituted with intravenous unfractionated or subcutaneous low-molecular-weight heparin until before the procedure.

SELECTION OF BALLOON CATHETER

Selection of an appropriately sized balloon catheter for the controlled stepwise dilatation technique is extremely important in order to avoid creating severe mitral regurgitation during BMV. Our balloon catheter selection methods have evolved from our continuing efforts to minimize this complication [4, 15–17] (Table 28.1).

Selection guidelines are based on balloon reference size derived from patient height, transthoracic echocardiographic findings of the mitral valve, and fluoroscopic presence of valvular calcification. The reference size (RS) is calculated according to a simple formula [16]: p. Patient height (in cm) is rounded to the nearest zero and divided by 10, and 10 is added to the ratio to yield the RS (in mm); e.g. if height = 147 cm, then RS = 150/10 + 10 = 25 mm. In patients with pliable, noncalcified valves and with angiographic mitral regurgitation ≤1+, a catheter with a nominal balloon size at least that of the RS (an RS-matched catheter) is used. In contrast, in patients at high risk for creating severe mitral regurgitation (valvular calcification and/or severe subvalvular lesions), a balloon catheter one size smaller than an RS match is selected. Therefore, in the above example with an RS of 25 mm, a PTMC-26 catheter would be selected for a pliable, noncalcified valve, and a PTMC-24 catheter for a calcified valve and/or a valve with severe subvalvular disease.

Tips and Tricks

****Pretesting for balloon–syringe mismatch** Although the volume predefined by red marks on the syringe and its corresponding balloon size at full inflation have been tested by the manufacturer, balloon–syringe mismatch may occur. While this mismatch is usually mild,

Table 28.1 Catheter selection and balloon sizing based on patient height and valvular status

Reference size (RS) (mm)	
Height (cm) (rounded to nearest 0) × 1/10 plus 10, e.g. height = 147 cm RS = 150 × 1/10 + 10 = 25 mm	
Catheter selection	
Valvular status	**Balloon catheter**
Pliable	RS matched (e.g. PTMC-26 for RS = 25 mm)
Calcified/severe subvalvular lesions	One size < RS matched (e.g. PTMC-24 for RS = 25 mm)

gross mismatch may take place when the catheter and the syringe are from different packages or reused after sterilization. The mismatch, if undetected, may result in either underinflation or overinflation of the balloon. The former may result in suboptimal valvular dilatation, and the latter in severe mitral regurgitation. Therefore, before inserting the balloon catheter into each patient, the balloon diameters should be confirmed using a two-step test. First, the syringe should be filled with diluted contrast to the mark corresponding to the balloon diameter chosen for the first inflation (see "Balloon Sizing"). The balloon should then be fully inflated, and its diameter measured with a caliper. If there is a mismatch, the difference should be noted and adjusted during the second step of testing when the balloon is inflated to its nominal diameter.

After the pretesting exercise, the syringe is disconnected from the balloon catheter for two reasons. One is to purge the syringe of any remaining air, and the other is to avoid any inadvertent overinflation of the balloon at its nominal size. After the catheter has been inserted into the left atrium, the air-free syringe filled with diluted contrast corresponding to the predetermined initial balloon diameter is reconnected to the catheter.

ADVANCEMENT OF BALLOON CATHETER

Insertion of the stretched Inoue balloon catheter over the 0.025-in. stainless steel coiled-tip guidewire into the right femoral vein is smooth in the majority of patients. There are four factors that influence the movement of the balloon due to resistance to the catheter at the femoral access site or at the interatrial septum (Figure 28.10).

Femoral Vein Access

To avoid creating a long subcutaneous tunnel, which may pose some resistance during insertion of the balloon catheter, the puncture needle is angled more vertically than usual during the initial vascular access (at about 60° to the skin surface). After transseptal puncture and

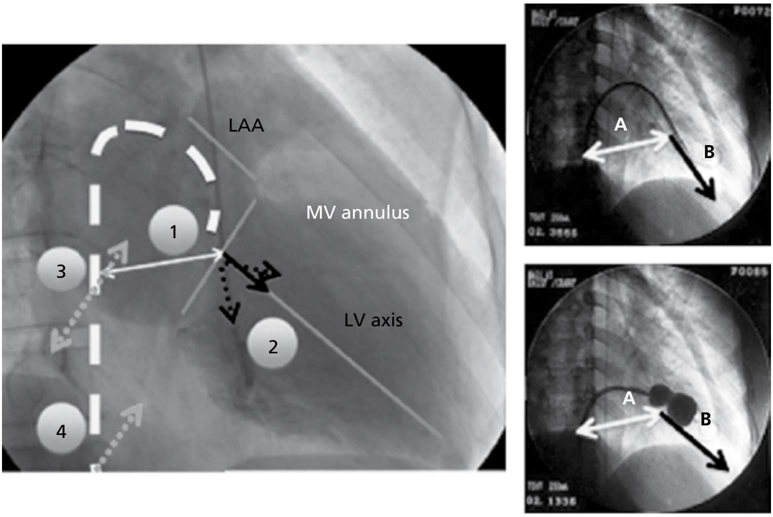


Figure 28.10 The four factors that influence the advancement of the Inoue balloon are (1) the width of the curve at the tip of the stylet; (2) the direction of the tip of the stylet; (3) the resistance at the septum; and (4) the resistance at the iliac artery area.

insertion of the coiled-tip guidewire into the left atrium, the subcutaneous track is well stretched with an artery forceps along the guidewire. This is followed by use of the 12-Fr dilator (enclosed in the Inoue balloon assembly set), which is also used to dilate the interatrial septum. Finally, when inserting the stretched balloon catheter, firm compression with the flat of the fingertips cephalad to the puncture site and over the subcutaneous track may be needed to aid catheter entry.

Tips and Tricks

****Resistance at groin access site** If significant resistance is encountered during insertion of the stretched balloon catheter, it is inserted into the vein at a more obtuse angle of about 90° until the catheter tip meets the posterior venous wall. The catheter is then tilted more horizontally and advanced over the wire. During the latter process, to facilitate catheter insertion and avoid bending the guidewire, firm compression should be applied cephalad to the puncture site and over the subcutaneous track (as described previously), and the guidewire should be held taut by an assistant. If this technique fails, the subcutaneous track and the vein should be re-dilated with the 14-Fr dilator. If these precautionary measures are exercised, the need for a 14-Fr intravascular sheath for insertion of the balloon catheter is rare in our experience, even in patients whose right groin is scarred from previous catheterization. However, one should not hesitate to use a 14-Fr vascular sheath to avoid bending the guidewire or metal tube when difficulty is encountered during the catheter insertion process.

It is also important to note that, during insertion of the catheter into the femoral vein, the catheter should never be twisted lest the metal tube be bent. If the tube is inadvertently bent, it should be replaced with a new one. On the other hand, if the guidewire is bent, the 12-Fr dilator is reinserted over the wire and carefully passed into the left atrium to permit guidewire exchange.

CROSSING THE MITRAL VALVE

At first, the balloon catheter is introduced under frontal fluoroscopic view into the atrium over the coiled-tip guidewire to form a large loop with the tip medial to the mitral orifice, pointing in a 6 to 7 o'clock direction (Figure 28.11). This placement has the following advantages: (1) the catheter thus positioned is less likely to flip to the left atrial appendage when the stylet is advanced to the catheter tip; (2) the catheter will not enter the pulmonary veins; and (3), in subsequent manipulations to cross the mitral valve, the deep-seated catheter will need only to be withdrawn. Thus, potential entrapment by a tough septum, which is only encountered during catheter advancement, is avoided (see "Catheter Entrapment at Atrial Septum).

After deep catheter placement in the left atrium, the fluoroscopic projection is changed from a frontal to a 30° RAO view (Figure 28.11b) that displays the left ventricular long axis in profile. In patients with giant left atria, additional use of the lateral fluoroscopic view may be needed to facilitate crossing of the valve.

With the stylet inserted to the catheter tip, the partially inflated distal balloon is directed toward the anteriorly located mitral orifice by applying a counterclockwise twist (usually 270°) to the stylet with the right hand (in a right-handed operator). The catheter is then withdrawn slowly, using the left hand, until a horizontal bobbing motion of the balloon is noted, indicating close proximity of the balloon to the mitral valve. The factors that influence the crossing of the balloon include the size of the left atrium and the position of the septal puncture site. They are highlighted in Figure 28.12.

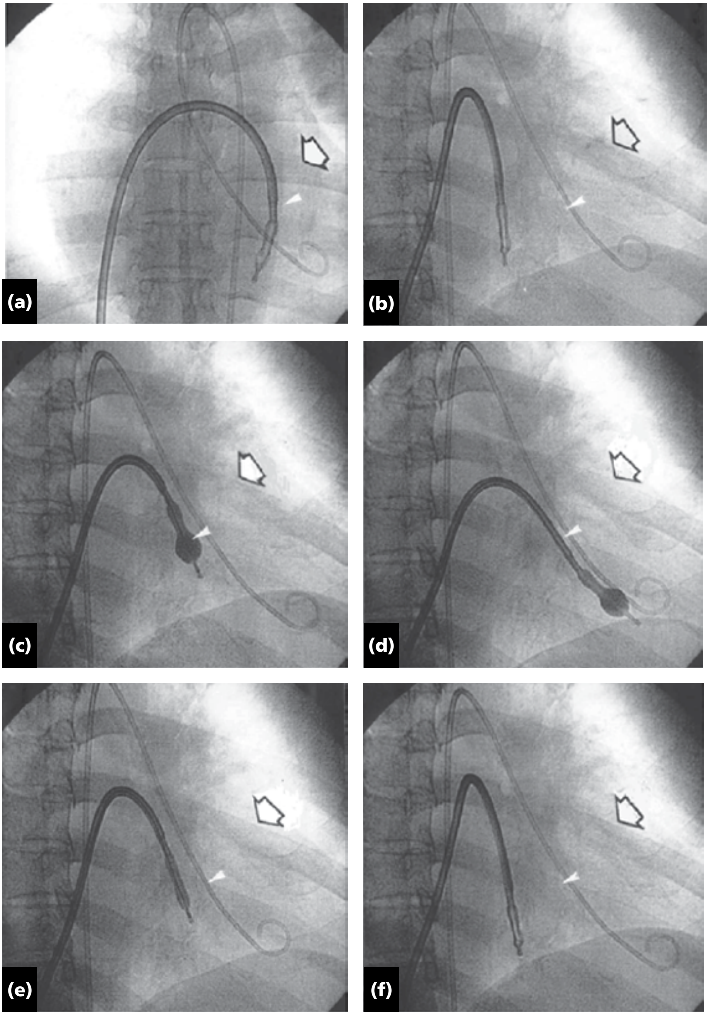


Figure 28.11 (a) A balloon catheter is introduced under frontal fluoroscopic view into the left atrium over the coiled-tip guidewire to form a large loop with the tip medial to the mitral orifice, pointing in the 6 to 7 o'clock direction. (b) After the deep catheter placement, the projection is changed to a 30° right anterior oblique view, and with the stylet inserted into the catheter tip, the partially inflated distal balloon is directed toward the anteriorly located mitral orifice. (c) The catheter is then withdrawn gradually to direct the balloon to the mitral valve (white arrowhead) and to cross the mitral valve (d). (d) After the balloon inflation procedure, the catheter balloon is withdrawn to the left atrium. In subsequent crossing of the mitral valve with the stepwise dilation technique, the stylet is inserted on the catheter tip (e), and the catheter is advanced to deep-seat the balloon (f). During balloon catheter manipulation under a 30° right anterior oblique fluoroscopic view, the catheter tip should always be kept to the left of the pigtail catheter preplaced in the left ventricle to avoid trespassing on the left atrial appendage area (open arrowhead).

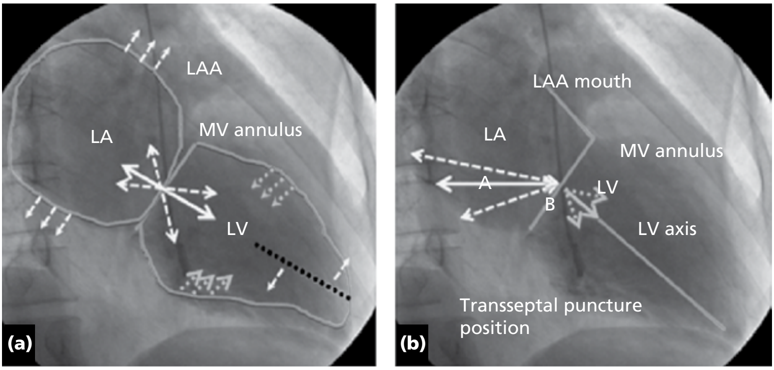


Figure 28.12 The anatomic factors that impact the crossing of the balloon into the left ventricle. (a) Impacts of severity of mitral valve stenosis on left atrium and left ventricle size and axis. (b) Impacts of transseptal puncture position and mitral valve plane on the direction of the Inoue balloon tip. LA = left atrium; LAA = left atrial appendage; LV = left ventricle; MV = mitral valve.

Methods of Crossing

Mitral valve crossing is then attempted using four methods in descending order of preference: (1) the vertical, (2) the direct, (3) the sliding, and (4) the posterior loop method. The vertical method is the most frequently successful crossing method.

The vertical method Upon further slight retraction of the catheter, the balloon is observed to move in (during diastole) (Figure 28.13a–d) and out (during systole) of the left ventricle (Figure 27.13e) even though the catheter is not aligned with the orifice–apex axis. Coincident with diastole, only the stylet is withdrawn. To accomplish this, the operator must carefully watch the rhythmic motion of the heart. This allows the distal segment of the catheter to take on a more horizontal orientation to cross the valve and enter deep in the left ventricle (Figure 28.13e–g). If the distal portion of the catheter is still vertically oriented and points to the inferior wall of the left ventricle (Figure 28.13g), the catheter is carefully withdrawn to align it with the orifice–apex axis (Figure 28.13h). During the process, the distal balloon may need to be inflated further to prevent it from popping out of the ventricle. This vertical approach keeps the catheter from inadvertently flipping into the appendage, thus minimizing the risk of catheter encroachment into the left atrial appendage in cases with thrombi confined to the appendage [18].

The direct method When the vertical method fails, the balloon catheter is further withdrawn until the catheter balloon is near the valve and the catheter is well aligned with the orifice–apex axis. At this time a "woodpecking" sign is observed as the balloon moves away from the mitral orifice in systole and toward it in diastole along the mitral–apex axis. Once this sign is evident, the balloon is in position to cross the mitral orifice. With careful attention to the rhythmic motion, the operator jerks the stylet back slightly (4–5 cm) as the balloon approaches the orifice and simultaneously advances the catheter with the left hand to drive the balloon across the valve deep into the left ventricle. Because timing is critical, in an operator's early experiences with BMV, selection of patients with sinus rhythm is recommended, as it is then easier to make use of the regular cardiac cycle to advance the balloon across the mitral orifice.

****Septal resistance** After atrial septal puncture and placement of the coiled-tip guidewire in the left atrium, occasionally there may be some difficulty in advancing the balloon catheter across the septum, particularly when the latter is markedly thickened at the puncture site. When this occurs, forceful action is to be avoided, as the catheter may curve excessively in the inferior vena cava, resulting in abdominal discomfort for the patient. Rather, the balloon catheter should be turned slightly, usually in a clockwise direction, as it is pushed forward (screwdriver maneuver) to overcome septal resistance. In the rare instances when this method also fails, the septum is re-dilated with the dilator. After passage across the septum, it is also

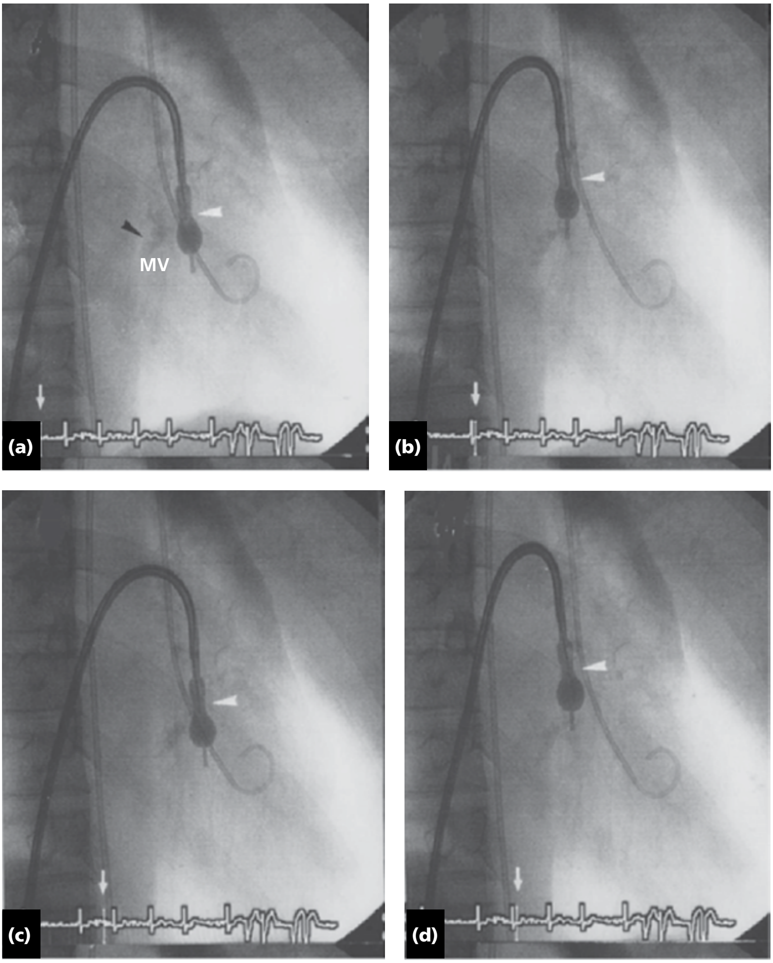


Figure 28.13 Vertical method. Fluoroscopic 30° right anterior oblique views during manipulations of the Inoue balloon catheter to cross the mitral valve. (a–d) During diastole (a and c) the catheter balloon crosses the calcified mitral valve (black arrowhead) into the left ventricle, while during systole (b and d), it pops back into the left atrium. (e) During diastole of the same cardiac cycle in (d), only the stylet is withdrawn, and the distal catheter thus adopts a more horizontal orientation, permitting the balloon to enter into the left ventricle. (f–h) The catheter is retracted to align along the left ventricular long axis. White arrowheads indicate the stylet tip position. White arrows at the bottom of each frame depict the timing of the cardiac cycle on the electrocardiogram. (See text for discussion.) Source: Reproduced with permission from [18] / HMP Global.

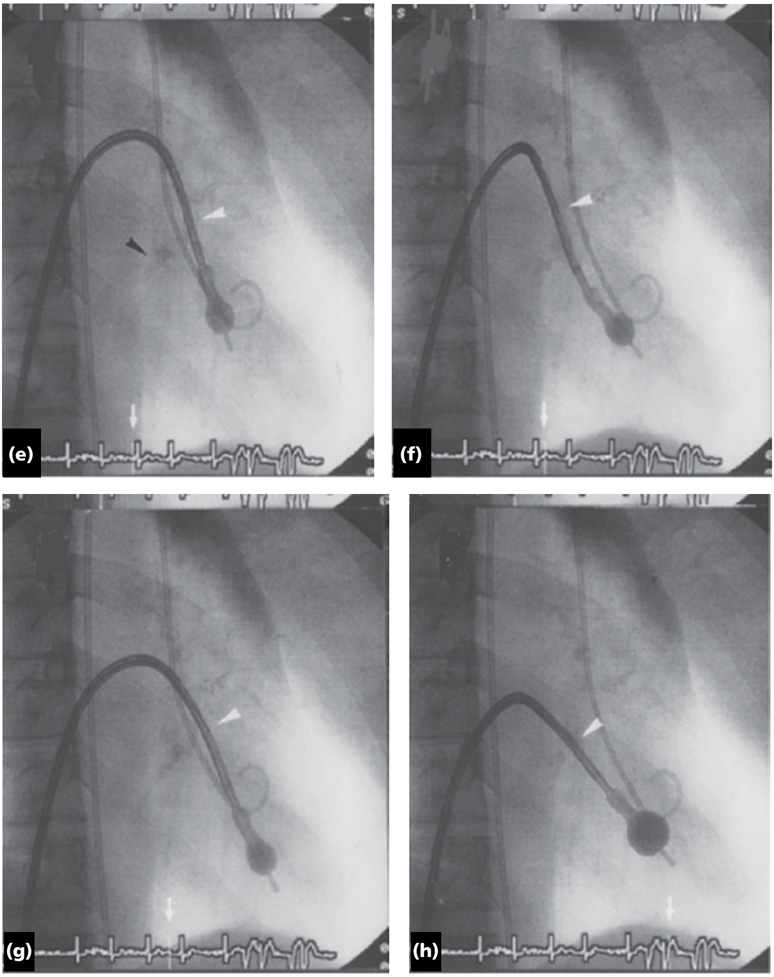


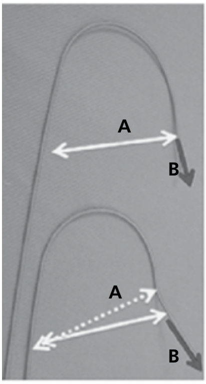
Figure 28.13 (Continued)

important not to push the catheter tip up against the left atrial roof, or the guidewire may be bent into an acute angle, making subsequent catheter manipulation difficult.

****Reshape the tip of the stylet** In the vertical and direct methods, it is important to insert the spring-wire stylet all the way to the balloon catheter tip to straighten the latter. Occasionally, however, the stylet may be too short to reach the catheter tip, thus making a slight bend in the catheter tip. If this occurs, the rubber grip at the proximal end of the stylet can be pulled further back to lengthen the exposed segment of the stylet, or, failing this, the rubber grip is cut at 1–2 mm from its distal end and removed. There are three kinds of shapes: A, B, and R (Figure 28.14).

To maintain the anterior orientation of the balloon (toward the mitral valve), the stylet must be kept twisted at all times. An extra counterclockwise twist is occasionally needed to direct the catheter tip anteriorly, especially in cases with giant left atria. In these cases, the septum is displaced markedly to the anterior, and thus the balloon catheter tends to point more posteriorly.

Reshape the tip of the stylet



- Reshape A to adapt the stylet width to the distance between the transseptal puncture position and MV orifice (A).
- Reshape B to adapt the stylet tip direction to the direction of LV axis (B).

R-shape stylet is usually required for:

- *Inappropriate (too low) septal puncture position*
- *Short distance between septal puncture position and mitral valve orifice*
- *Too horizontal LV axis …*

***R-shape stylet* (*3D*)**

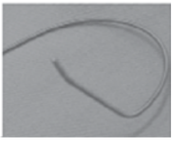


Figure 28.14 Types of shapes of the tip of the stylet.

An added lateral fluoroscopic view will facilitate manipulation of the catheter/stylet for balloon crossing of the mitral valve in these instances (Figure 28.15).

The catheter sliding method When the vertical or direct method fails, another technique that may be useful for crossing the mitral valve is the catheter sliding method [15]. This method has proved to be effective in cases when the septal puncture is made too caudally and/or the left ventricle takes a more horizontal orientation (Figure 28.16a). The balloon is first directed toward the mitral valve by keeping the stylet twisted counterclockwise. The distal catheter segment is then made more flexible by withdrawing the stylet clear out of the balloon segment (Figure 28.16b). Once the slightly inflated balloon is at the mitral orifice, cardiac contractions will cause the balloon segment to tilt upward during systole (Figure 28.16c). In diastole, the balloon segment aligns with the catheter shaft (Figure 28.16d). With the operator carefully watching the rhythmic motion of the cardiac cycle, only the catheter is advanced forward (with the stylet kept fixed) during diastole to cross the valve (Figure 28.16e). The stylet is then advanced to help align the catheter with the orifice–apex axis (Figure 28.16f).

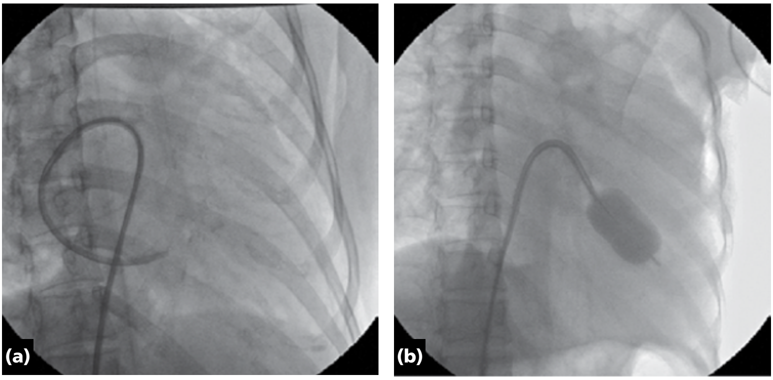


Figure 28.15 (a) The balloon formed a big loop in the left atrium in order to be able to cross the valve. (b) After crossing the valve, the Inoue balloon catheter returns to its usual position for inflation.

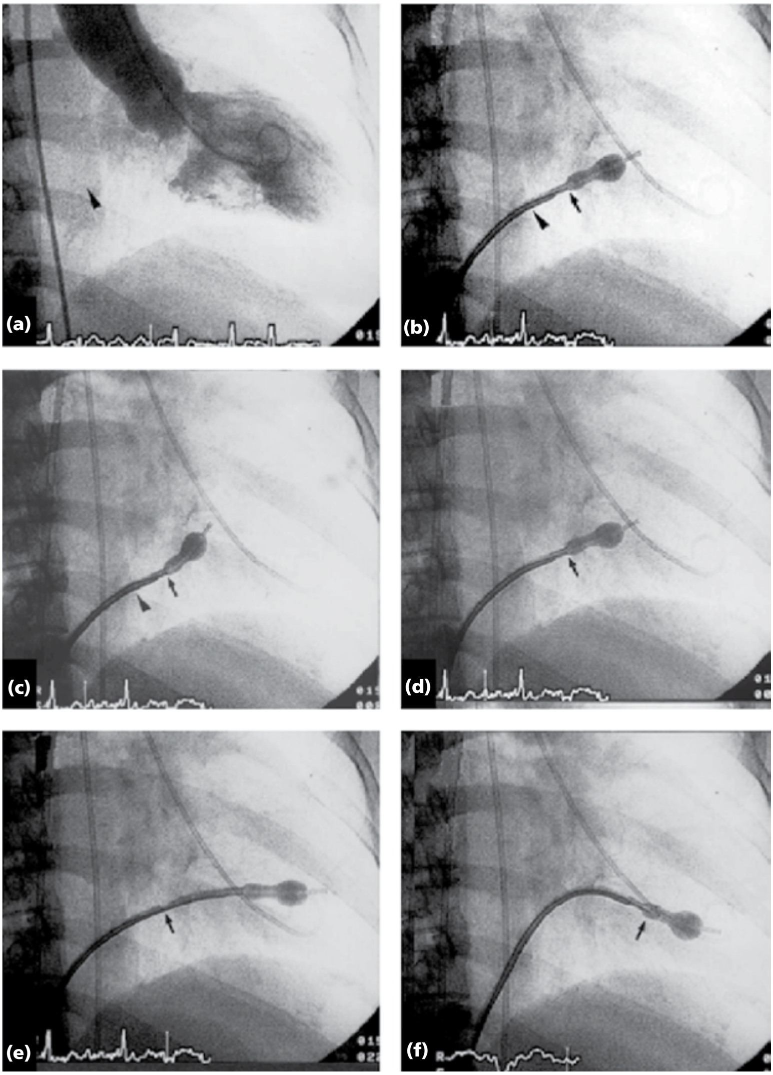


Figure 28.16 Catheter sliding method. (a) Left ventriculogram in 30° right anterior oblique view, showing the position of the transseptal puncture site (arrowhead), quite caudal to the mitral orifice; the left ventricle is more horizontally oriented. (b) The stylet (arrow) is slightly withdrawn from the balloon segment. (c,d) During a cardiac cycle, the balloon segment bobs up and down in systole and diastole, respectively, indicating proper positioning of the catheter tip at the mitral orifice. (e) During diastole, when the balloon bobs down and is aligned with the distal catheter (as in d), only the catheter is advanced forward (with the stylet kept fixed) to place the balloon in the left ventricle. (f) Thereafter, the stylet is carefully advanced to align the catheter with the mitral orifice/ventricular apex axis before initiating the balloon inflation procedure. Reproduced with permission of Wiley.

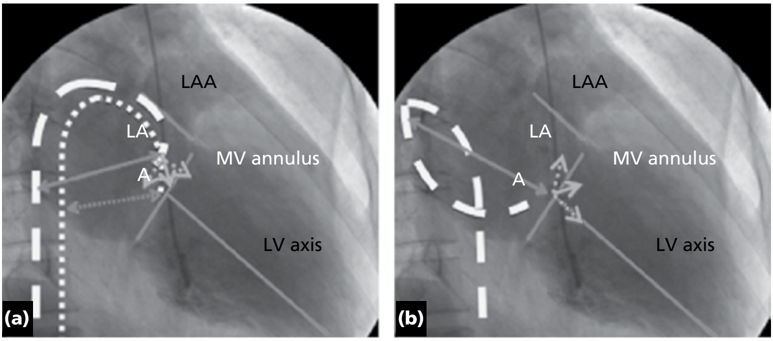


Figure 28.17 Adjusting the width of the stylet in order to cross the mitral valve. (a) Adjust the stylet width (A) according to the left atrium diameter (small/large) or transseptal puncture position (low/high). (b) Further increase the stylet width (A) for giant left atrium (alternative driving technique).

The posterior loop method Crossing the valve with the balloon catheter may be difficult with the previously described methods in patients with giant left atria or when the atrial septal puncture has been made inappropriately, either too cephalad or too anterior in relation to the mitral valve. In such circumstances, the posterior loop approach may be used. This method, which has been well described previously [15], is infrequently used in these authors' experience.

Tips and Tricks

****Stylet reshaping** The J-tipped stylet with its original curve will, in most instances, steer the balloon toward and across the mitral orifice. However, when it is difficult to direct the balloon toward the mitral orifice by aligning the catheter with the orifice–apex axis, the stylet should be reshaped according to the positional relationship between the septal puncture site and the valve orifice (Figure 28.17). For example, in patients with a giant left atrium where the puncture is often made more caudally and laterally in relation to the mitral orifice, the distal segment of the stylet can be shaped into a larger smooth curve to facilitate passage of the balloon across the mitral valve. Conversely, in those with a relatively small left atrium, when the puncture site is made suboptimally, either too medially or anteriorly (in relation to the mitral valve), the stylet can be reshaped into a tighter loop (or the posterior loop method can be employed).

****Why is a big loop in the left atrium needed?** The first reason is to avoid trapping in the septum or the pulmonary veins. It is also to avoid entering the left atrial appendage. The second reason is to have more length in the shaft of the catheter in order to have more control in the manipulation of the balloon during alternate driving (Figure 28.18).

BALLOON INFLATION

Assuring Free Balloon Movement in the Left Ventricle

One of the most dreaded complications of BMV is the development of severe mitral regurgitation requiring surgery. Once the mitral valve has been crossed, the free movements of the partially inflated distal balloon in the left ventricle should be ascertained to prevent the disastrous consequences, i.e. rupture of chordae, papillary muscles, or leaflets, stemming from its

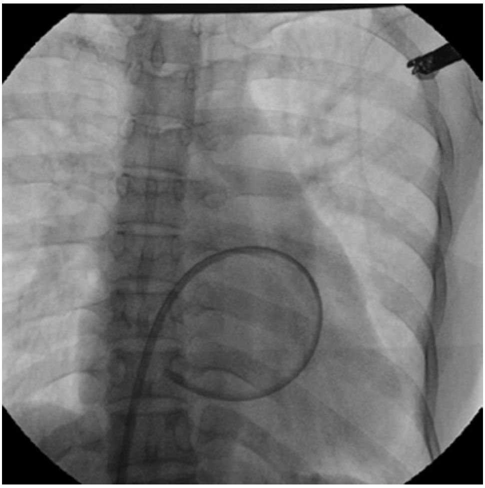


Figure 28.18 The tip of the Inoue balloon catheter makes a big loop in the left atrium.

subsequent full inflation between the chordae. This is done by simultaneously pushing the catheter and pulling the stylet slightly in opposite directions ("accordion" maneuver) [15] to ensure that the partially inflated distal balloon slides freely along the orifice–apex axis.

Tips and Tricks

****If the balloon strays among the chordae** After crossing the mitral valve, the catheter balloon may point more vertically and deviate away from the orifice–apex axis. This suggests that the catheter has strayed among the chordae. To correct this situation, the distal balloon is inflated larger to prevent the balloon from being inadvertently retracted into the atrium, and the catheter is carefully pulled back to assume a more horizontal orientation. After satisfactory alignment of the catheter with the orifice–apex axis, the catheter is advanced toward the apex, and the previously described accordion maneuver is performed before initiating the inflation procedure. Similarly, a twist in the balloon during the inflation process may also indicate that the catheter has tethered among the chordae. In this case, the inflation should be promptly aborted and the balloon repositioned.

Reassessment of Subvalvular Status

Before BMV, mitral valvular status is determined by pre-procedural transthoracic echocardiography and fluoroscopy (for the presence of valvular calcification), and an appropriate balloon catheter is then chosen accordingly (see "Selection of Balloon Catheter"). Extensive subvalvular disease has been found by various investigators to be a predictor for significant mitral regurgitation. Echocardiography (either transthoracic or transesophageal) often underestimates the severity of subvalvular disease [15], and so severe mitral regurgitation may be created during BMV despite the presence of an apparently favorable valve morphology. Therefore, during the actual balloon dilatations, vigilance is required to identify the presence of previously undetected severe subvalvular diseases. We and others have found other, more reliable, signs of significant subvalvular involvement [17, 19]. Even in patients in whom no severe subvalvular disease is demonstrated by pre-procedural echocardiography, when any of the signs described in the following paragraphs are observed, the balloon dilatation protocol is altered accordingly as described under "Balloon Sizing."

Tips and Tricks

****Severe subvalvular disease undetected by echocardiography** The following signs suggest or indicate the presence of severe subvalvular disease.

1. Difficulty in performing the accordion maneuver. This occurs because of resistance at the subvalvular level. If this difficulty is not appreciated, subsequent full balloon inflation will be within the left ventricle as the balloon is not anchored at the mitral valve. Hence, it is the subvalvular apparatus and not the mitral valve that is dilated. Although severe mitral regurgitation may result from such an accidental subvalvular dilatation [19], the inflation is usually harmless. However, it should be promptly recognized, and the balloon quickly deflated. The size of the distal balloon is then reduced during subsequent attempts to anchor the balloon at the mitral valve.
2. Gross indentation of the inflated distal balloon (balloon compression sign) (Figure 28.19a). This indicates severe subvalvular disease [17]. As soon as compression is observed on the distal balloon, the inflation procedure is aborted and the inflation strategy is reassessed.
3. "Balloon impasse" (Figure 28.19f). In cases of tight mitral stenosis, valve crossing may be difficult even when the catheter, with its distal balloon partially inflated, is properly aligned with the long axis of the left ventricle. If this occurs, the size of the balloon is gradually reduced until it is accommodated by the mitral orifice. In rare and extreme instances, even when the balloon is not inflated, the catheter is checked (or entrapped) at the mitral valve. This finding, which we have termed "balloon impasse," reflects resistance caused by severe obstructive subvalvular lesions [17]. In the presence of this sign, BMV performed with the usual catheter selection and balloon sizing is likely to tear the mitral leaflets and/or chordae and thus create severe mitral regurgitation. Our experience in a limited number of patients suggests that in addition to stepwise dilatations previously emphasized, the use of smaller balloon catheters may prevent the complication of severe mitral regurgitation [17].
4. Cogwheel resistance. Rarely, while withdrawing the partially inflated balloon to anchor it at the mitral valve, cogwheel resistance may be encountered. This suggests the presence of subvalvular disease.

CONTROLLED STEPWISE DILATATIONS

In order to avoid or minimize the complication of severe mitral regurgitation, the selection of an appropriate balloon catheter (see "Selection of Balloon Catheter") and the controlled stepwise dilatation technique are mandatory. In addition, one should be familiar with the pressure–volume relationship and inflation limit of the less compliant balloon of the second-generation catheter now in use [16].

Balloon Pressure–Volume Relationship

The intra-balloon pressure transits from the "low-pressure" to the "high-pressure" zone as the balloon is inflated to within 2 mm of its nominal size, e.g. the 24- to 26-mm zone in a 26-mm balloon catheter. Each catheter can be safely inflated to a maximal diameter of 1 mm above the nominal size because of the built-in safety margin. Initial balloon inflation is never to be performed with balloon diameter in the high-pressure zone regardless of the valvular morphology.

Balloon Sizing

Balloon sizing for the stepwise dilatation technique is crucial in avoiding the complication of severe mitral regurgitation (Table 28.2). Our balloon sizing methods have evolved through our continuing efforts to minimize this complication. By adhering to the cautionary methods outlined here, especially in patients with severe subvalvular disease, the creation of significant mitral regurgitation (increase of ≥2+ angiographically) can be minimized.

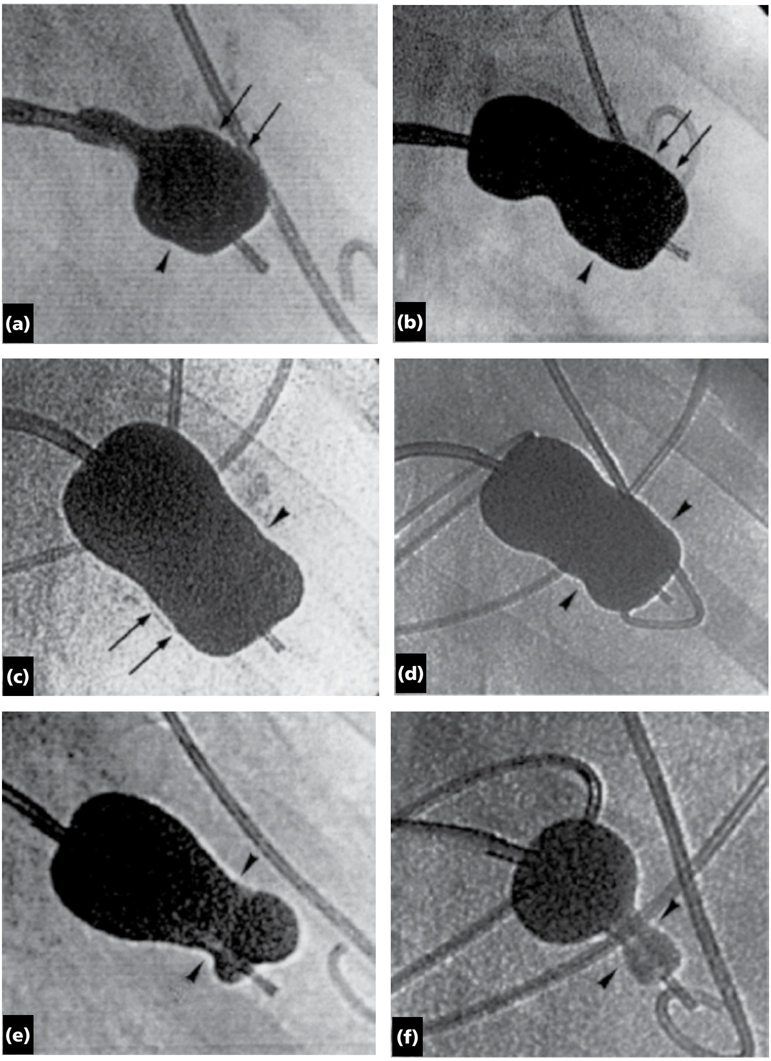


Figure 28.19 Various deformities of the inflated balloon caused by severe subvalvular disease. (a–e) Indentation (arrowheads) and compression (arrows) are observed on the distal balloon segment. (f) During in situ test inflation of the balloon at the mitral valve, the proximal but not the distal segment is inflated as the latter is compressed (arrowheads) by severe subvalvular disease (see text for discussion).

Tips and Tricks

****Balloon sizing in patients with pliable, noncalcified valves** In patients with pliable, noncalcified valves and no severe subvalvular lesions, as determined by the subvalvular reassessment outlined previously, an RS-matched balloon catheter is selected as stated previously. The initial inflated balloon diameter is RS - 2 mm. In subsequent dilatations, the balloon size is increased by 1 mm. When there is preexisting mitral regurgitation or any question of

Table 28.2 **Balloon sizing based on patient height and valvular status**

Valvular status	Initial	Increments
Pliable	(RS - 2) mm	1 mm, or 0.5 mm in high-pressure zone[a] (if MR or unilateral commissural split)
Calcified/SL	(RS - 4) mm	1 mm (low-pressure zone[b]) 0.5 mm (high-pressure zone[a])

MR, mitral regurgitation, preexisting or increased; RS matched, catheter with its nominal balloon size ≥RS; SL = severe subvalvular lesions.

[a] High-pressure zone = balloon diameter within 2 mm of nominal balloon size.

[b] Low-pressure zone = balloon diameter < 2 mm of nominal balloon size.

increase in the degree of mitral regurgitation, the increment should be 0.5 mm in the high-pressure zone. This approach also applies when unilateral commissural splitting occurred during the previous dilatation, as observed by an asymmetric balloon waist on fluoroscopy. The final diameter is best kept within 1 mm above the RS to avoid oversizing: our previous study [17] showed that oversizing of the balloon is a risk factor for creating severe mitral regurgitation in this group of patients.

****Balloon sizing in patients with calcified valves and/or with severe subvalvular disease** In patients with either fluoroscopically visible valvular calcification or severe subvalvular lesions as observed by transthoracic echocardiography, instead of an RS match, a balloon catheter one size smaller than the RS match is selected at the outset. For those whose subvalvular lesions are not detected by pre-procedural echocardiography, the RS-matched catheter already placed in the patient may still be used if the dilatation procedures are carried out with extra care. Ideally, the catheter should be exchanged for a smaller one, but this is quite costly.

For the first dilatation, a balloon diameter 4 mm less than the RS is used. For subsequent dilatations, the balloon size is increased by 1 mm in the low-pressure zone and by 0.5 mm in the high-pressure zone until satisfactory results are obtained or until mitral regurgitation develops. In cases where the gradient has already been reduced to one-half and several more dilatation attempts have failed to reduce it further, the procedure is terminated to avoid creating severe mitral regurgitation. [16]. Reducing the mitral valve gradient by one-half should result in a 41% increase in the mitral valve area, as calculated by the Gorlin formula, provided that heart rate and cardiac output remain the same. Our previous study [16] suggests that a 40% improvement in the valve area is sufficient for symptomatic improvements in patients with a more sedentary lifestyle.

****Balloon sizing in cases of "balloon impasse"** If balloon impasse (Figure 28.19f) is encountered, the initial catheter is exchanged for a smaller PTMC-18 or – 20 catheter to pre-dilate the valve and the subvalvular structures, regardless of the echocardiographic findings of the mitral valve [17]. We no longer force the usual-sized balloon through the valve to the left ventricle by slenderizing and stretching the deflated balloon segment, as previously recommended [2], nor do we recommend advancing the balloon across the mitral valve over a guidewire preplaced in the left ventricle. Both maneuvers may cause the catheter to stray among the chordae, and with larger-sized balloon catheters it is difficult or impossible for the operator to execute the precautionary "accordion" maneuver to ensure that the catheter is not tethered among the chordae.

However, if a smaller PTMC-18 or – 20 catheter also fails to cross the mitral valve with the catheter uninflated, the balloon segment of this small balloon catheter is slenderized and stretched for crossing the mitral valve. Before the balloon inflation procedure, it is mandatory to exercise the "accordion" maneuver with the distal balloon slightly inflated to ensure that the balloon catheter is free in the left ventricle. This maneuver would not have been possible with larger-sized catheters. The initial inflation is then performed with the balloon diameter at its nominal size. If further dilatations are required, the catheter is exchanged for one a size larger, and stepwise dilatations are done according to the sizing method in patients with severe subvalvular lesions, as discussed previously.

Exchange for Different-sized Balloon Catheters

Exchange of balloon catheters is carried out for two reasons. The first, as alluded to earlier, is to downsize the catheter because of the "impasse" posed by severe subvalvular distortions.

The second reason is the rare instance when there is a need to upsize the balloon catheter to one that is one size larger because of inadequate hemodynamic improvement. In such a situation, before exchanging for a larger catheter, it is vital that the initial catheter's final balloon diameter be remeasured and reverified after its complete removal from the patient, particularly when it has been inflated beyond its nominal size. This precautionary exercise is essential because, not uncommonly, despite pretesting, the balloon size is smaller than it is supposed to be after in vivo usage. When this occurs, the original balloon catheter is retested to determine the actual volume of diluted contrast in the syringe necessary to achieve maximum balloon size (as mentioned previously, the Inoue balloon tolerates about 1 mm in excess of its nominal size before rupturing), the original balloon catheter is reintroduced into the patient, and the dilatation process is repeated. However, if the balloon matches its predefined size, an exchange for a larger-sized catheter is made, and dilatations with the larger balloon are performed. Failure to reverify maximum balloon size before inflating a much larger balloon creates the risk of severe mitral regurgitation.

Tips and Tricks

****Balloon "popping" to the left atrium** When the mitral valve has already been enlarged by dilatations, the balloon may occasionally slip into the left atrium during subsequent inflations with larger balloon diameters. To prevent the latter from occurring, the stylet is advanced far into the balloon segment to stiffen the catheter, and before the catheter is retracted to anchor the balloon at the orifice, the distal balloon is inflated to a diameter slightly larger than the previous one. As soon as the balloon assumes an hourglass configuration, the catheter is advanced slightly to prevent it from jerking out into the left atrium, and full balloon expansion is then executed. With this extra dilatation, although the mitral gradient may be unchanged, further shortening of the A_2–opening snap interval and enhanced splitting of the commissures, as assessed by echocardiography, are often observed.

The balloon "popping" signals enlargement of the mitral orifice with wide splitting of the commissures. It is usually encountered in patients with pliable, noncalcified valves and foretells excellent BMV results. However, suboptimal hemodynamic results are occasionally observed despite the balloon "popping" sign, especially in the presence of atrial fibrillation. In these cases, although the mitral valve with split commissures can be forced to accommodate the fully inflated balloon, the effective mitral valve area is, in reality, limited by the thickened and stiff leaflets and by ineffective atrial contractions in the beating heart.

****Subsequent valve crossings and dilatations** After the initial balloon inflation procedure, the catheter balloon is withdrawn to the left atrium while keeping the catheter tip to the left of the pigtail catheter. The effects of the balloon dilatation are assessed by observing the left atrial pressure waveforms and measuring the transmitral gradient and also by auscultation. If mitral regurgitation is suspected by the advent of a large v-wave and by a new or worsening systolic murmur, echocardiography or left ventriculography may be performed. In subsequent crossings of the mitral valve with the stepwise dilatation technique, the stylet is inserted to the catheter tip, and the catheter is advanced to deep-seat the balloon. Thereafter, the previously described manipulations are repeated to cross the mitral valve for valve dilatations.

****Catheter entrapment at atrial septum** When the septal puncture site is thick and tough, the catheter may be entrapped by the septum, thereby making manipulations difficult during subsequent attempts at crossing the mitral valve. The operator should be alert to the possibility of this entrapment when marked resistance is encountered at the septum during septal puncture. This vexing problem usually does not occur during the first crossing of the valve because, as alluded to earlier, the catheter is already deeply placed and coiled in the left atrium. However, entrapment may occur during subsequent crossings when it becomes necessary to advance the catheter, which has been inadvertently withdrawn too far back into the atrium after valvular dilatation and is caught at the thick septum. If the catheter cannot be advanced with the stylet inserted all the way to the catheter tip, a clockwise twist is applied to the stylet, directing the catheter tip posterolaterally to align it more or less perpendicular to the septal plane. The catheter may then be advanced forward together with the stylet (Figure 28.20). If even this approach fails, the coiled-tip guidewire should be reinserted to facilitate deep placement of the catheter in the left atrium.

****Avoiding the left atrial appendage** Left atrial appendage thrombus may be unsuspected when BMV candidates are screened only with insensitive transthoracic echocardiography. To minimize the risk of inadvertent thrombus dislodgement and systemic embolism, the anterolateral appendage region must be avoided. During balloon catheter manipulation performed under 30° RAO fluoroscopic view, the catheter tip should always be kept to the left of the pigtail catheter preplaced in the left ventricle (Figure 28.11). After avoiding the situations detailed above, it may be possible to perform BMV safely even in the presence of left atrial appendage thrombi [20, 21].

The alternatives are either to subject patients with appendage thrombi to mitral valve surgery or to defer BMV for stable patients until resolution of the thrombi after warfarin treatment [21].

****Withdrawing the catheter from the ventricle** After each balloon inflation procedure, in order to exert better control over the catheter tip and to prevent it from encroaching on the left atrial appendage, the stylet is advanced halfway into the balloon segment, and a slight clockwise twist to the stylet is applied as the catheter is withdrawn back to the left atrium. The balloon catheter, with its tip thus directed posteriorly, can then be safely pulled to the atrium by cautiously withdrawing the catheter and the stylet in steps. The catheter, however, should not be withdrawn too far during the process (see "Catheter Entrapment at Atrial Septum"). The stylet is then removed entirely from the catheter for left atrial pressure measurement, leaving the deflated balloon segment pointing vertically. Again, during hemodynamic measurements, care should be exercised to avoid accidentally pushing the catheter forward into the appendage.

****Subsequent crossings** The catheter, after having been withdrawn from the left ventricle, stands fairly straight up without looping. Thus, for the next crossings of the mitral valve, extra care is needed to keep the catheter to the left of the pigtail catheter. The stylet is carefully inserted to the catheter tip to bend the catheter downward into a generous arch with the distal catheter segment oriented more vertically (Figure 28.11). Then a counterclockwise twist to the stylet is made, and the catheter is slowly withdrawn to direct the partially inflated balloon toward the mitral valve.

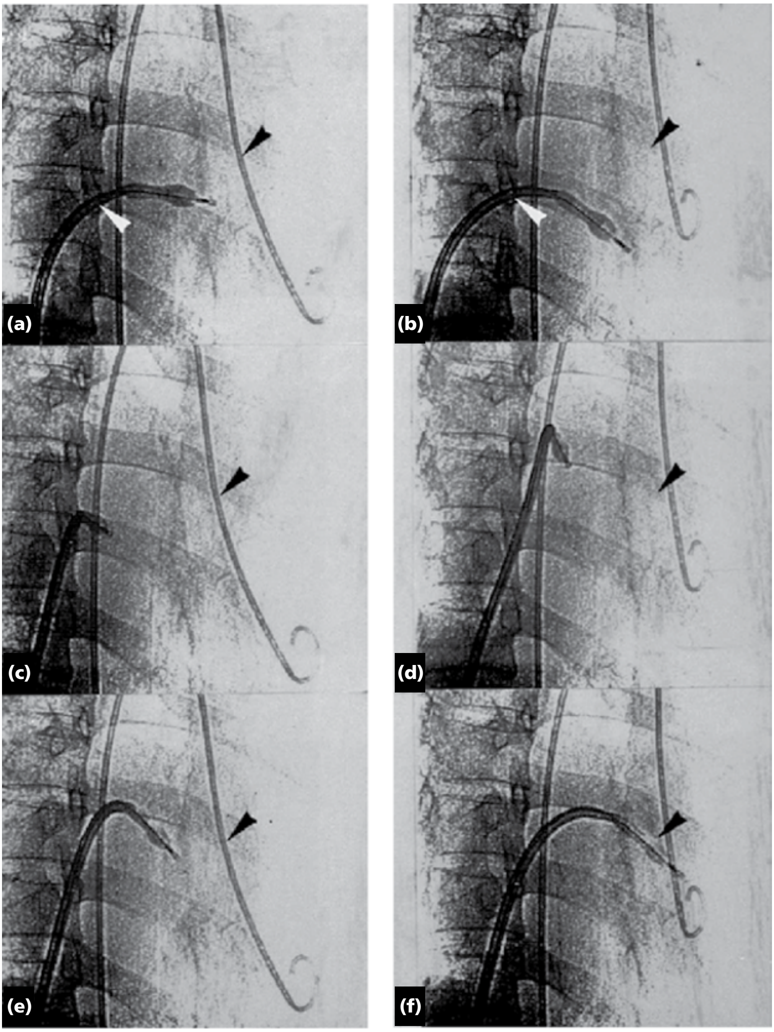


Figure 28.20 Sequence of steps to disengage a catheter entrapped in a thick septum. (a) The balloon catheter with the stylet inserted to the tip is entrapped at the atrial septum (white arrowhead). (b) When the catheter is pushed, it does not advance forward but rather turns downward. (c) A slight clockwise twist is made to the stylet to direct the catheter tip posteriorly. (d) The catheter, now aligned more or less perpendicular to the septal plane, can be effectively advanced further into the left atrium. (e) A counterclockwise twist is now made to the stylet to direct the catheter tip anteriorly. (f) The catheter is carefully withdrawn to bring its tip toward the mitral orifice (black arrowhead).

Table 28.3 Tips and tricks for challenging BMC cases

Situation	Reasons	Solutions
Left ventricular (LV) axis directions	Horizontal LV	Puncture high and small stylet width
	Vertical LV	Puncture low and R-shape stylet
	Posterior LV	Use AP view instead of RAO 30° view
	Dextrocardia	Change imaging view (flip vertical)
Left atrium size and septal puncture position	Giant LA	Alternative (loop) way to drive balloon
	Low puncture (big LA)	Big stylet width and long R-shaped stylet
	Trapped in septum (low puncture)	Well dilated and make a big balloon loop in LA to facilitate balloon control
	Trapped in pulmonary veins (small LA)	Small stylet width and make balloon big loops in LA before driving balloon
	High puncture (small LA)	Small stylet width and keep balloon deeply inside LA
	LAA thrombus	Use the aortic pigtail as a marker
Mitral valve	Unequal calcification	Sliding technique rather than direct technique

AP = anterior–posterior; LA = left atrium; LAA = left atrial appendage; LV = left ventricle; RAO = right anterior oblique.

PREVENTION OF COMPLICATIONS

In general, BMV is a complex and invasive procedure. The problems and tips and tricks in order to solve them are summarized in Table 28.3.

Tips and Tricks

****Avoid entry into the left atrial appendage** It should be noted that the catheter has a propensity to enter the left atrial appendage if the catheter tip is more horizontally oriented and the stylet is pulled back too vigorously during a failed crossing attempt. To avoid this, the stylet should not be withdrawn too much during any manipulation in the left atrium, particularly when the sliding or posterior loop method is used.

****Minimizing atrial septal injury** Inherent in the antegrade BMV approach is the creation of an atrial septal defect. Fortunately, most of these defects are small and of no clinical consequence, and they tend to close spontaneously with time.

To minimize the occurrence of these defects and to avoid septal avulsion, a number of precautionary steps should be adopted. First, before full balloon inflation, i.e. after the balloon has attained its hourglass configuration and is securely anchored at the mitral valve, the distal segment of the catheter shaft (between the septal puncture site and the balloon) should be allowed to take on a gentle curve by releasing the tension exerted on the balloon catheter during its placement across the mitral valve. Second, it is mandatory to adhere to the standard practice of balloon slenderization during balloon passage across the septum (on both entry into and withdrawal from the left atrium). Third, before removing the stretched balloon catheter from the left atrium to the right atrium, the guidewire should be withdrawn, leaving only its soft distal floppy segment exposed. This may avoid "slicing" of the septum by the stiff portion of the wire during withdrawal of the catheter/wire assembly.

****Bent balloon tip** Kinking of the stretched balloon occurs during placement of the catheter in the left atrium if the guidewire is withdrawn before releasing the inner tube

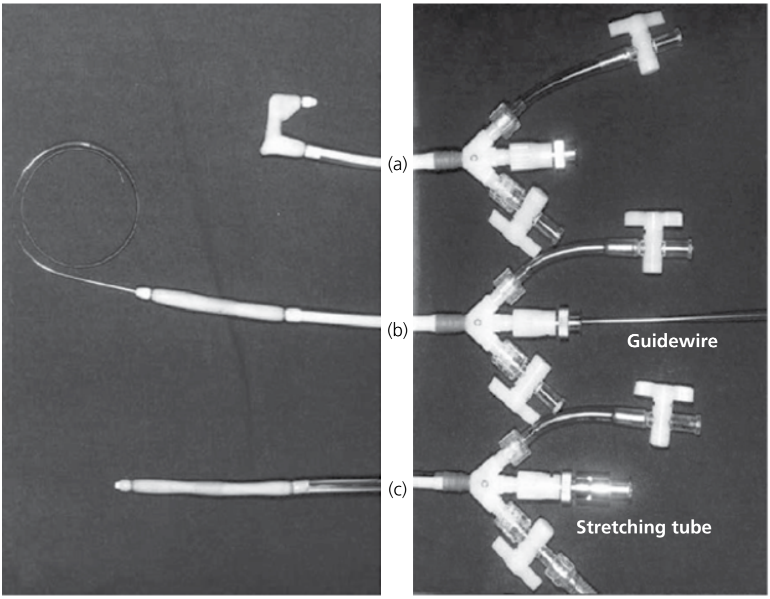


Figure 28.21 Kinked balloon. (a) Kinking of the unsupported balloon segment occurs when the inner tube is pushed to stretch the catheter balloon. (b) Balloon segment supported by guidewire. (c) The balloon segment is supported by stretching the tube.

from its locked position. The balloon segment, unsupported by either the metal tube or the guidewire, may also be inadvertently bent by advancing the inner tube alone. Once the tip is bent, subsequent attempts at crossing the mitral valve with the catheter may be extremely difficult, if not impossible. In addition, it may be impossible to reinsert the guidewire to retrieve the balloon catheter from the left atrium. This problem may be overcome by (1) pulling the inner tube to its limit to shorten the balloon segment; (2) carefully inflating the entire balloon in the left atrium to sufficiently straighten the kinked inner tube; and (3) passing the guidewire through the deflated balloon to reestablish its natural shape (Figure 28.21).

****How to prevent mitral regurgitation** Some patients are at high risk for severe mitral regurgitation after BMV. They have heavily calcified commissures and leaflets and shortened/fused chordal and subvalvular apparatus. They also have preexisting moderate mitral regurgitation, severe tricuspid regurgitation, and thrombus in the left atrial appendix. In these situations, a few tips for PTMV include:

1. Be sure that the balloon moves freely and coaxially with the LV axis before dilatation.
2. Avoid balloon inflation in the subvalvular apparatus (“accordion” maneuver).
3. Perform stepwise dilatation, following the sizing guideline based on the valve status.
4. Avoid pulling back too hard when the balloon is fully inflated.

****How to prevent pulmonary embolism** PTMV is an invasive procedure involving the right heart, and there is therefore a chance of pulmonary embolism. Some tips include:

1. Pre-procedural transesophageal echocardiography is obligatory in patients with atrial fibrillation or high-risk patients in order to exclude left atrial thrombus, new thrombus in the left atrial appendage, or thrombus protruding into the left atrium.

2. Heparin bolus (2000–5000 IU) after the transseptal puncture.
3. Regular and meticulous flushing of the catheter during the procedure.
4. Shorten the procedural time, especially when the balloon is on the left side of the heart.
5. Use special techniques to drive the Inoue balloon if thrombus is present in the left atrial appendage.

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CHAPTER 29

Watchman™ Left Atrial Appendage Closure Device

Ajoe John Kattoor, Mihas Kodenchery, Hieu H. Truong, and Sandeep Sehgal

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

Nonvalvular atrial fibrillation is associated with an increased risk of stroke [1]. Unfortunately, many patients are unable to tolerate anticoagulation (i.e. warfarin/Coumadin, newer oral anticoagulants) due to bleeding, fall risk, cost, and side effects. As the majority of thrombi originate in the left atrial appendage (LAA), the stroke risk can also be mitigated by excluding flow into the LAA. Over the last decade, advances in medical technology have made percutaneous LAA closure (LAAC) devices an attractive alternative to treat these patients [2].

The Watchman™ LAAC device has been extensively studied over the last 15 years [2–5]. Follow-up studies, both in Europe and the United States, have confirmed its noninferiority to warfarin with regard to stroke, systemic embolism, and cardiovascular death, while demonstrating reduced rates of peri-procedural complications [6–9]. The high procedural success rates and low complications, even among relatively inexperienced operators, are reassuring [10]. Although data are encouraging, it is imperative to emphasize the importance of case planning before a LAAC procedure as well as having meticulous procedural techniques.

GAME PLAN

Imaging is the most critical component of the Watchman LAAC procedure. Previously, preprocedural transesophageal echocardiography (TEE) or cardiac coronary computed tomography angiography was used for planning and assessing feasibility. However, with improved experience in Watchman Flx (Boston Scientific, Marlborough, USA) implantation, many institutions now forgo preprocedural assessment except when there is suspicion of LAA removal/ligation from prior cardiac surgeries or in patients with a high risk of thrombus who are not currently on anticoagulation. This approach avoids an additional procedural visit for the patient and potentially reduces the risks associated with TEE and its related anesthesia.

TEE imaging should cover four main views of the LAA: 0°, 45°, 90°, and 135°. Multiplanar views are essential to fully understand the LAA's anatomy, including size, morphology, number of lobes, and presence of thrombus. In these views, both the width and length of the LAA should be measured and matched against the device chart for accurate sizing [11] (Table 29.1). Proper performance and interpretation of these views by the operator are crucial to minimizing errors in estimating the LAA ostium size and required implant depth. This step reduces the risks of undersizing, which can lead to leaks and the need for upsizing, as well as oversizing, which can cause complications like device embolization due to insufficient anchoring, LAA perforation, and cardiac tamponade. Incorrectly sized Watchman Flx devices may fail to properly deploy and engage with the LAA, increasing the risk of device embolization and migration. The presence of LAA thrombus is currently a contraindication for the placement of the Watchman Flx device. The newer generation, Watchman Flx Pro, features a hemocompatible coating that may promote faster endothelialization, potentially improving device-related thrombus rates. Additionally, this version includes a new 40-mm size and radiopaque markers to aid in device placement.

Table 29.1

Max LAA Ostium Width and/or Deployed Closure Device Diameter (mm)*	Closure Device Size (mm)
14.0 – 18.0	20
16.8 – 21.6	24
18.9 – 24.3	27
21.7 – 27.9	31
24.5 – 31.5	35
28.0 – 36.0	40

* The LAA depth should be approximately half the labelled Implant diameter or longer.

VENOUS ACCESS

Ultrasound-guided right transfemoral venous access is the preferred method for Watchman Flx implantation. The left transfemoral vein can also be utilized if the right femoral venous access is not available. Initially, a short sheath (6–8 Fr in size) is placed, which is then upsized to a 16-Fr long sheath for the insertion of the Watchman Flx delivery sheath (18 Fr for Watchman TruSteer Sheath, Boston Scientific, Marlborough, USA), using a stiff wire. The VersaCross wire (Baylis, Montreal, Quebec, Canada) may be employed to advance the sheath, thereby eliminating the step of exchanging it for another stiff wire. Inserting the delivery sheath directly without using a 16-Fr sheath is possible, but it can be challenging to manipulate and may cause kinking of the delivery sheath; therefore, this approach is not recommended. The presence of an inferior vena cava (IVC) filter is not a contraindication for the procedure. Usually, the sheath can be carefully maneuvered across the IVC filter, allowing the procedure to be completed without issues.

ACCESS CLOSURE

One or two Perclose Closure devices (Abbott Vascular, CA, USA) can be placed in a “preclose” fashion after obtaining access, and these can be tightened at the end of the procedure to achieve hemostasis. Alternatively, a Figure-of-8 or mattress suture can be used to approximate the subcutaneous tissue to achieve hemostasis.

TRANSSEPTAL ACCESS

TEE guidance is recommended for transseptal access, as it allows for direct visualization and facilitates the identification of an appropriate site for septal crossing. Previously, mechanical and radiofrequency (RF) needles were used for transseptal access. However, the introduction of the VersaCross-VersaConnect transseptal system (Baylis, Montreal, Quebec, Canada) has significantly simplified and expedited the process. The Watchman Delivery sheath dilator (Boston Scientific, Marlborough, USA) is replaced with the VersaConnect dilator (Baylis, Montreal, Quebec, Canada), which is then introduced into the body over the VersaCross wire. Once the sheath and dilator reach the superior vena cava (SVC), the VersaCross wire is withdrawn into the dilator. The sheath and dilator are then pulled down in a clockwise direction under TEE guidance to the interatrial septum at the desired location for the transseptal puncture (Figures 29.1).

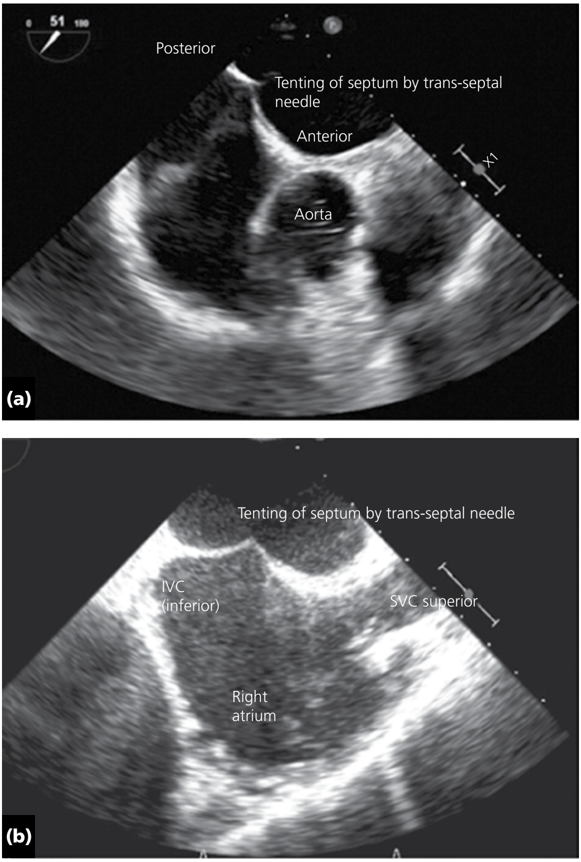

0 51 180
Posterior
Tenting of septum by trans-septal needle
Anterior
X1
Aorta
(a)
Tenting of septum by trans-septal needle
IVC (inferior)
SVC superior
Right atrium
(b)

Figure 29.1 (a) Aortic short axis showing the anterior-posterior aspects of the interatrial septum. (b) In the bicaval view, the inferior-superior aspect of the interatrial septum is demonstrated. IVC = inferior vena cava.

Tips and Tricks

Before introducing it into the patient, the VersaConnect dilator curve should be made prominent outside the body. A larger curve facilitates better contact and tenting of the interatrial septum. A larger curve is preferred if the right atrial size is dilated. However, an excessively large curve may complicate catheter manipulation.

Caution

Avoid advancing the VersaCross wire directly out of the dilator/sheath, except when performing interatrial septal puncture, to prevent inadvertent puncture of cardiac structures. If repositioning is necessary, withdraw the dilator/sheath over the VersaCross wire to expose its pigtail portion before advancing it. The pigtail curve of the VersaCross wire is relatively safe for direct advancement, but the tip is sharp and stiff when it emerges from the dilator/sheath system.

The long axis of the LAA is oriented anteriorly, while the plane of its ostium lies at a 90° angle to this direction. The transseptal crossing must allow the Watchman delivery sheath to be placed with adequate depth in the LAA for coaxial deployment. Therefore, a posterior-anterior trajectory is ideal. Visualization using TEE, specifically the short axis and bicaval views, will guide the correct access point, thereby increasing the ease and success of the procedure. Generally, the transseptal crossing should be in an inferior posterior position. Access that is too superior or anterior can complicate coaxial device deployment. A pre-existing patent foramen ovale is not the ideal site for transseptal access, although it may be used in certain anatomies. Scanning the LAA to assess the trajectory when tenting is made on the interatrial septum can help determine if the puncture site is appropriate. The RF is switched "on" for 2 seconds, followed by advancement of the VersaCross wire into the left atrium. Once transseptal access is achieved, a VersaCross stiff wire is placed in the left upper pulmonary vein, and the VersaConnect dilator and Watchman sheath are advanced into the left atrium.

Heparin should be administered prior to crossing the interatrial septum, targeting an activated clotting time of over 250 seconds. With the introduction of the VersaConnect system, the number of sheath exchanges has been minimized, leading many operators to administer a full dose of heparin immediately after venous access. Some operators prefer to give a half dose of heparin after venous access and the remaining half after the transseptal puncture.

Caution: Wire Perforation

Avoid advancing the dilator sheath system if the VersaCross wire is not located in the left atrium, as it may have inadvertently punctured the aorta or the right atrial wall. If wire perforation occurs, complications can typically be managed percutaneously if the dilator is not advanced.

SHARP THINKING

Undersized LAA Due to Relative Dehydration

The pressure should be measured after transseptal crossing with the Watchman sheath. If the left atrial (LA) pressure is <10 mmHg, consider intravenous hydration to increase the atrial pressure, as low pressure could lead to the appearance of a "smaller" LAA and result in undersizing of the Watchman device. This may rarely result in late device embolization/migration.

LEFT ATRIAL APPENDAGE MORPHOLOGY

There are three well-described morphologies for the LAA relating to Watchman placement: windsock, chicken wing, and broccoli. The LAA should be imaged in the right anterior oblique (RAO) 30° caudal 20° (close to TEE 135°). The windsock LAA is one where the dominant lobe of sufficient length is the primary structure. The chicken wing LAA has as its main feature a sharp bend in the dominant lobe of the LAA anatomy at a distance from the visualized LAA ostium. The main feature of the broccoli LAA is a limited overall length/depth with more complex distal anatomy, but it can have sufficient ostial width. Some authors describe a fourth morphology known as "cactus shaped," with a dominant central lobe and secondary lobes that arise from it superiorly and inferiorly. There are, of course, multiple variations of these types of anatomies (e.g. broccoli with a chicken wing, etc.). Success of the procedure will depend on accurate determination of ostial and depth measurements (Figure 29.2).

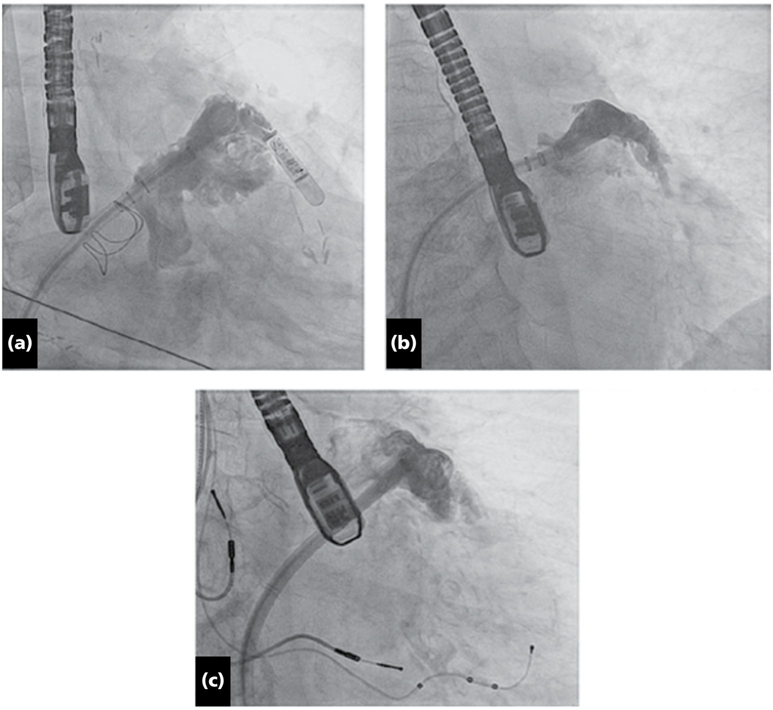


Figure 29.2 Morphology of the left atrial appendage (LAA). (a) Broccoli shaped LAA; (b) chicken wing shaped LAA; (c) wind sock shaped LAA.

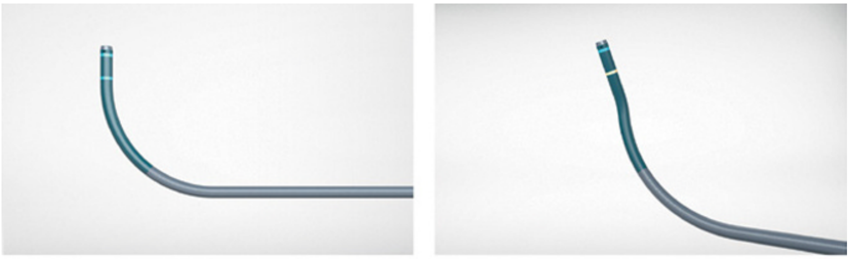
SELECTION OF THE SHEATH

Currently, there are two types of sheaths available for Watchman device placement: Watchman FXD curve sheaths and Watchman TruSteer sheaths (Figure 29.3). Although the double-curve Watchman FXD sheaths have been used in the vast majority of reported cases, there are situations where the other types of sheaths may be more beneficial. The optimal sheath choice can be determined using the 135° view on TEE. This view allows the operator to adequately visualize the distal lobes of the LAA and decide which sheath is most suitable. Superior lobes generally angle medially and anteriorly, while inferior lobes tend to extend laterally and posteriorly.

A traditional windsock LAA, or uncomplicated chicken wing or broccoli morphologies, can usually be accessed with a double-curve sheath. This sheath provides the best options, particularly in multilobed LAAs. A posterior or leftward orientation of the LAA is better suited for a single-curve sheath. The operator can determine the anterior or posterior direction of the sheath using the angiographic image in an RAO caudal view. The newer Watchman TruSteer sheath allows for a wider range of motion and thereby more coaxial alignment of the device to the LAA ostium.

Tips and Tricks

****Which lobe is ideal for deployment?** Which lobe is ideal for deployment? In a multi-lobed LAA, the most distal lobe may not always be the best location for deploying the device.



Single Curve: Tighter Curve Radius Optimized for More **Posterior** Anatomies

Double Curve: Distal Curve Optimized for More **Anterior** Anatomies

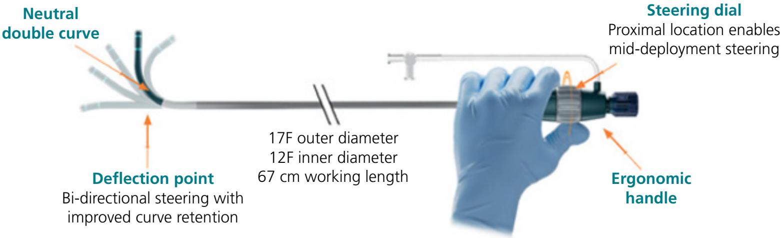

Neutral double curve
Steering dial
Proximal location enables mid-deployment steering
17F outer diameter
12F inner diameter
67 cm working length
Deflection point
Bi-directional steering with improved curve retention
Ergonomic handle

Figure 29.3 Types of Watchman device sheaths. Top Panel: Watchman FXD curve sheaths –Left: single curve (for posterior anatomies) and Right: double curve (for more anterior anatomies). Bottom panel: Watchman TruSteer sheath with greater range of motion. https:// www.watchman.com/en-us-implanter/device/trusteer-access-system.html

It is crucial to use the 135° TEE view to determine which lobe will allow for the most coaxial deployment of the Watchman device. Ultimately, the goal is to position the Watchman device at a location that ensures a perfect seal of the LAA ostium.

LEFT ATRIAL APPENDAGE ACCESS

A standard 4- or 5-Fr pigtail catheter should be inserted within the Watchman sheath to locate the LAA. This approach is safer and less traumatic compared to maneuvering with the sheath alone, and it also allows for contrast injection. If the transseptal access was achieved in the inferior-posterior plane, gently turning the catheter counterclockwise with slow advancement should position it at the mouth of the LAA. This maneuver should be performed under TEE guidance to prevent inadvertent placement of the pigtail catheter across the mitral valve or into the left ventricle.

Tips and Tricks

****Difficult entries of the pigtail into the LAA** If the pigtail catheter cannot be advanced to the LAA despite counterclockwise rotation, consider pulling back the Watchman sheath minimally to allow more flexion of the pigtail catheter. It is absolutely critical that the sheath is pulled back only slightly so as not to be pulled back into the right atrium. Once the pigtail catheter is introduced into the LAA (as confirmed by TEE with or without angiogram), the sheath can then be advanced gently across the pigtail (which serves as a "rail") to be placed into the LAA. Both counterclockwise and clockwise motions may be needed to ensure that the sheath "follows" the pigtail catheter appropriately depending on the LAA anatomy.

****Manipulation of the pigtail catheter** It may be difficult to maneuver a pigtail catheter as a straight catheter into the LAA. A smaller French angled pigtail catheter can be used if the distal lobe(s) of the LAA is smaller. This can help facilitate a deeper placement of the sheath; however, this maneuver can be offset by less "rail" support for the sheath.

****Prolapse of the pigtail catheter with advancement of the sheath** Keeping the VersaCross wire partially within the body of the pigtail catheter can aid in its manipulation and provide stronger support for sheath advancement. If the sheath prolapses when advancing into the LAA, advancing the VersaCross wire within the pigtail, without exiting, can offer additional support.

Device Placement/Deployment

Once the sheath is positioned in the LAA, angiography is performed with a hand injection of contrast through either the pigtail catheter or the sheath to define the LAA's anatomy. The size of the Watchman device is confirmed by measuring the ostium and depth using the sheath as a marker (Figure 29.4). The sheath is carefully positioned deeper inside the LAA over the pigtail catheter, and the pigtail catheter is removed once the sheath is at the appropriate depth. Avoid advancing the sheath forward without the pigtail catheter leading, as this can result in perforation.

The Watchman Flx device is then inserted into the sheath and advanced toward the LAA. As the device delivery system nears the sheath's tip, the sheath is retracted to expose the device delivery system, locking the sheath and the Watchman Flx delivery system together as a single unit.

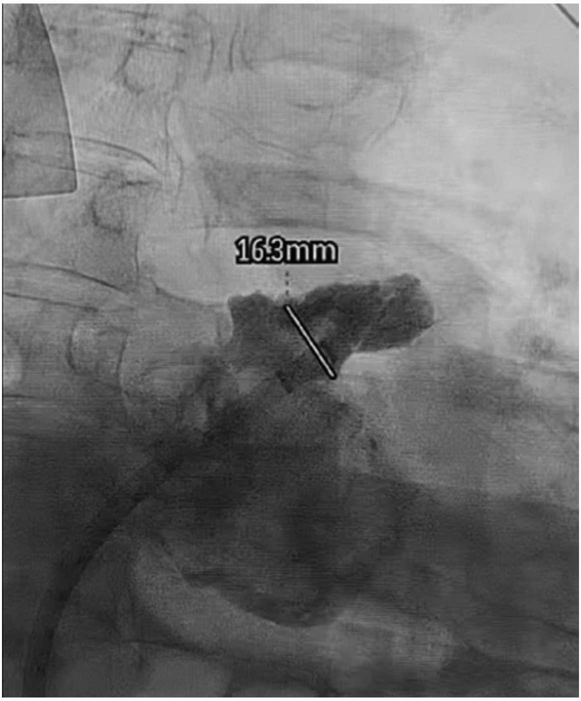


Figure 29.4 Measurement of LAA ostial size by fluoroscopy. LAA, left atrial appendage.

Warning

Prevention of air embolism is critical. Before the introduction of the Watchman device, careful attention must be paid to ensure no air is introduced into the system, and device preparation is critical to ensure that no bubbles are present in the system before it is advanced in the sheath.

The hemostasis valve is then loosened, and by fixing the right hand on the deployment knob and pulling the sheath and delivery system with the left hand toward the right hand, the device can be unsheathed until the "Flx ball" is formed (Figure 29.5). The "Flx ball" is generally atraumatic and can be maneuvered safely within the appendage if necessary. However, trabeculations may limit excessive manipulations once the "Flx ball" is formed. The "Flx ball" is designed to advance into the LAA, bending and sliding in a different direction when encountering significant resistance.

Caution: Avoid advancing the Watchman Flx device directly out of the sheath without forming the "Flx ball" shape, as this increases the risk of perforation. If deeper placement is required, always unsheathe to form the "Flx ball" and then advance with the "Flx ball" leading the sheath. Once the desired position is achieved, the Watchman Flx device is fully unsheathed.

Tips and Tricks

***Allow approximately 10 seconds for the device to fully expand and for its anchors to engage with the LAA. Subsequently, a tug test is performed to confirm anchor fixation. This test involves gently pulling the delivery cable after opening the hemostasis valve and monitoring for proximal displacement of the Watchman Flx device. On fluoroscopy, stability is indicated by the stable position of the distal fluoroscopic tip of the Watchman Flx. TEE images are also reviewed for stability and appropriateness based on the PASS criteria (Table 29.2).

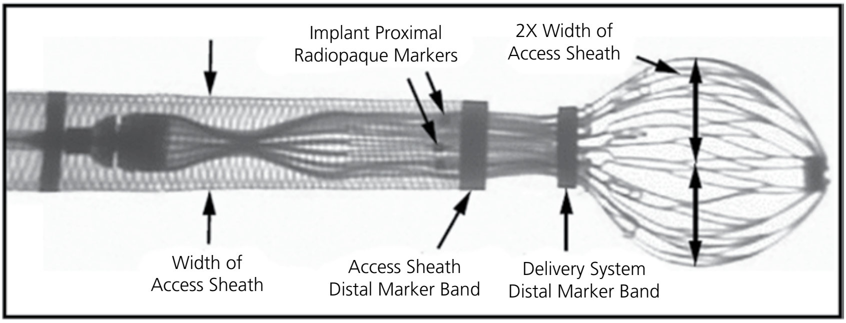

Implant Proximal Radiopaque Markers
2X Width of Access Sheath
Width of Access Sheath
Access Sheath Distal Marker Band
Delivery System Distal Marker Band

Figure 29.5 Formation of Flx Ball. Proper configuration of the implant and its radiopaque markers for positioning the closure device within the LAA.

Table 29.2 PASS Criteria. All criteria must be met before device release (PASS)

Position	**The device is distal to or at the ostium of the LAA; this should be visualized on multiple TEE views**
Anchor	Fixation anchors engaged/device is stable; this can be verified with the "tug test"
Size	The device is compressed to 10–30% of its original size
Seal	Device spans ostium; all lobes of LAA are covered

Once the PASS criteria are met, the device can be deployed with a counterclockwise rotation of the distal deployment knob. Before deployment, an angiographic confirmation in the RAO 20°/caudal 20° view can be performed for an additional assessment of leaks or placement.

*Spontaneous to-and-fro movement of the deployment knob when the hemostasis valve is opened usually suggests good engagement of the Watchman Flx device onto the LAA and is reassuring during the tug test.

TROUBLESHOOTING

Tips and Tricks

****What if the device is deployed too distally?** If the Watchman device is deployed too distally, resulting in a leak or exposed lobe, a "partial recapture" can be performed. This involves fixing the right hand on the deployment knob and using the right thumb and left hand to gently advance the catheter to "resheath" the device back to the "Flx ball" configuration. This disengages all the anchors, allowing the device to be withdrawn to the desired depth as a unit before performing the original release process again (see Figure 29.6). Deep implantation is a risk factor for device-related thrombus and therefore is best avoided.

****What if the device is deployed too proximally?** Perform a partial recapture of the "Flx ball" as described previously. The device can then be advanced, led by the "Flx ball," into the LAA. Avoid advancing the delivery system in a fully recaptured format, as it increases the risk of perforation. If the appropriate depth cannot be obtained, the device may need to be exchanged for a pigtail catheter to aid in selective engagement of the preferred LAA lobe and advancement of the delivery sheath. A renewed deployment attempt is then made.

****What if the device is deployed in the wrong lobe or is severely tilted/canted in a multilobed LAA?** First, perform a recapture of the Watchman device. Depending on the targeted lobe (anterior/posterior), the catheter will need to be torqued in a specific direction to disengage. In multilobed cases, a double-curve sheath provides more flexibility. Re-engage the desired LAA lobe with the "Flx ball" or a pigtail catheter as described previously.

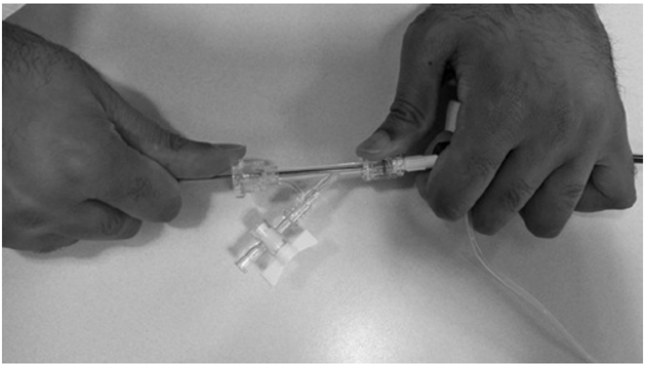


Figure 29.6 Partial recapture technique. After loosening the catheter port, the right hand is fixed on the distal device lever, and then the right thumb and left hand are utilized to gently advance the catheter to "resheath" the device (but only past the first "stop").

Use counterclockwise torque on the sheath for the anterior lobe; clockwise torque on the access system will orient the catheter toward the posterior lobe. If the sheath appears overly angulated or curved, it may indicate a suboptimal transseptal puncture location, preventing coaxial alignment of the sheath to the LAA long axis. In such cases, withdrawing the catheters and repeating the transseptal puncture at a more favorable location is often easier and timesaving.

****What if I need a different sheath?** Remove the existing sheath from the LAA (but not from the LA). Advance the initial stiff wire into the LA and left superior pulmonary vein, then remove the sheath. Introduce the new sheath (with dilator) across the atrial septum and proceed from the initial steps.

*****Manipulations not transmitting/kinked sheath?** Excessive manipulation during difficult LAA anatomy cases or inappropriate transseptal punctures can easily kink the sheath, often at the trans-septal puncture site. If torque is not transmitted or advancing the sheath is difficult, suspect kinking. If kinking occurs at any procedure point, immediately exchange the sheath over a stiff wire after removing the Watchman Flx device. Manipulation with a kinked delivery sheath is challenging and risky, as it can pin the delivery cable at the kink location and potentially unscrew the device during counterclockwise manipulations, leading to unintentional device release into the left atrium [12].

****What if there is a perforation?** In the event of a perforation, perform emergent pericardiocentesis as needed. Reverse heparin with protamine if the device/sheath can be removed. If the device is deployed but not detached, do not withdraw it, as this could worsen tamponade. If the device is properly seated and meets PASS criteria, detach it, then administer protamine. Obtain a surgical consult if the device is improperly seated or cannot be deployed or withdrawn. Notably, the Watchman Flx generally has a better safety profile regarding perforation, with most occurrences happening during transseptal puncture (Figure 29.7).

****Contraindication for TEE** In patients with contraindications for TEE, or if general anesthesia needs to be avoided, Watchman device placement can be performed using intracardiac echocardiographic (ICE) guidance. The latest 3D ICE catheters significantly reduce the need for

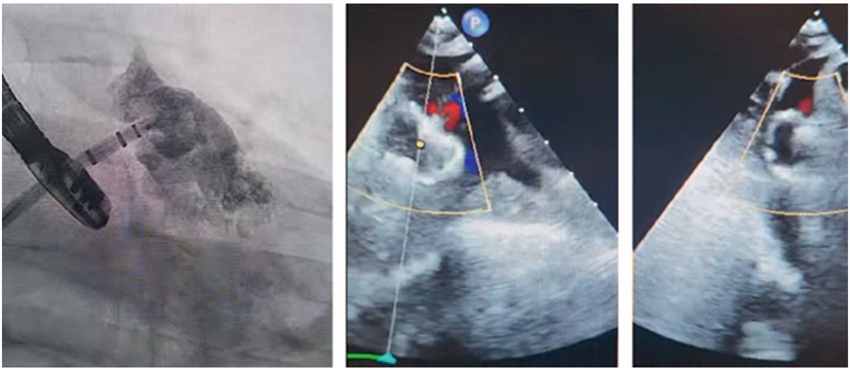


Figure 29.7 Watchman Flx Pro device perforates and gets deployed in the pericardial space. The patient developed cardiac tamponade, and emergent pericardiocentesis was performed. Around 1.8 L of blood was autotransfused, and the patient underwent surgical excision of the device and LAA ligation successfully.

extensive manipulations to obtain various views of the LAA. Typically, the ICE catheter is introduced through a long sheath placed via the left femoral venous access into the left atrium, either through the same transseptal puncture after dilating the interatrial septum with the Watchman sheath or via a separate transseptal puncture (Figure 29.8).

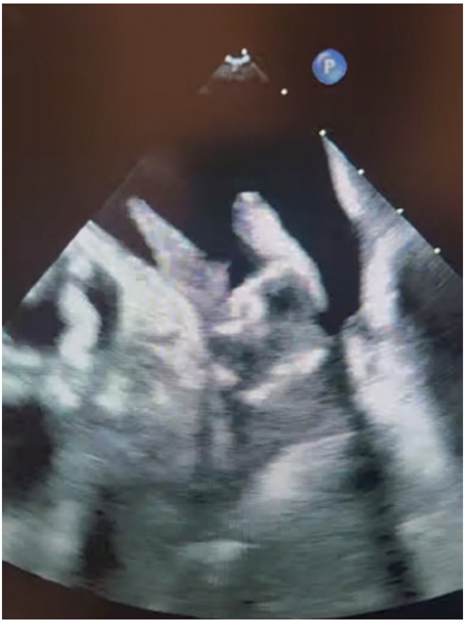


Figure 29.8 Device related thrombus in a patient with stroke after Watchman implantation. The thrombus resolved after placing the patient back on systemic anticoagulation.

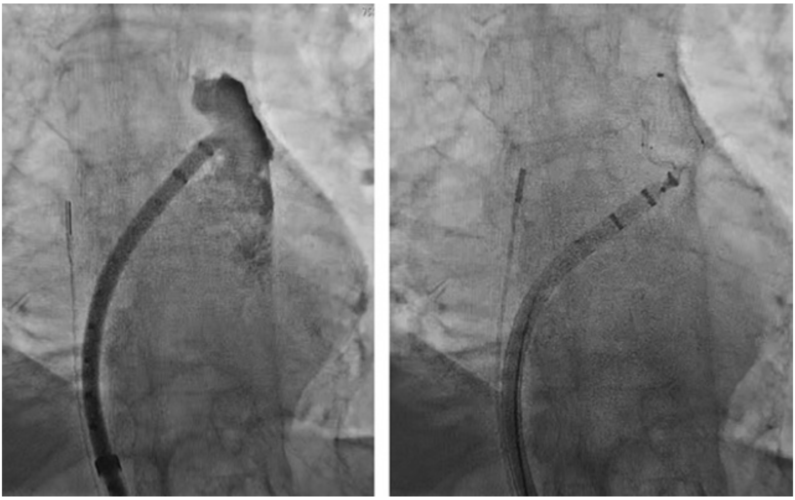


Figure 29.9 A challenging LAA anatomy with a tortuous heart. Intracardiac echo is used for guidance. The Watchman Flx Pro device was deployed with the aid of a Watchman TruSteer delivery sheath.

****Device embolization** If the Watchman Flx device embolizes into the left atrium, it can be retrieved using a Rapter snare and using at least an 18-Fr or larger sheath, usually a Gore dry seal sheath. If the device advances into the left ventricle, usually surgical removal is required to avoid damage to the valvular structures during removal (Figure 29.9).

ACTION POINTS

1. Case planning starts with imaging – only adequate visualization will help make implantation successful.
2. Transseptal puncture should be TEE or ICE guided for improved safety.
3. Access to the LA is critical – focus on a perfect transseptal puncture location rather than just "trying to get across."
4. Sheath choice should be reflective of the LAA anatomy in the 135° view on TEE, but usually the double-curved sheath is sufficient in most anatomies.
5. Deployment should be done in a smooth, gentle motion.
6. Utilize the PASS criteria. If no device can fit adequately, it is better to withdraw it rather than leaving it poorly placed. Newer devices optimal for the appendage anatomy may be available in the future.

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CHAPTER 30

Interventions in Acute Ischemic Stroke

Le Van Truong and Nguyen Trong Tuyen

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*Basic; **Advanced; ***Rare, exotic, or investigational
$, <100.00 $US extra; $$, >100.00 $US extra
⌛, <10 min extra; ⌛⌛, >10 min extra
💧, low risk of complications; 💧💧, high risk of complications

Practical Handbook of Advanced Interventional Cardiology: Tips and Tricks, Sixth Edition.
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CHALLENGES

Interventional neurology is a rapidly evolving field. Using the same techniques and modified equipment from interventional cardiology and radiology, operators in interventional neurology are successful in opening acutely occluded cerebral arteries in patients with large-vessel ischemic stroke. However there are plenty of challenges ahead.

BEST PLAYERS

aka Standard of Excellence

The Thrombolysis in Cerebral Infarction (TICI) Scale (Table 30.1) is a grading system tool for determining the results of thrombolytic therapy after ischemic stroke [1].

Cerebral arterial flow of TICI grade 2B and 3 is the criterion of successful revascularization in large-vessel acute ischemic stroke. However, after revascularization within 6 h of onset in patients with acute ischemic stroke, the condition of cerebral edema varies in each individual. The longer the delay in revascularization, or the lower the number of collaterals, the larger area of ischemia; therefore, there would be more severe cerebral edema even after successful and complete revascularization of the infarcted artery causing acute ischemic stroke.

GAME PLAN

Sedation In order to ensure that the interventional procedure can be performed safely and smoothly, the patient should be kept calm and relaxed. Conscious sedation or even general anesthesia is used if needed to ensure the smooth progression of the procedure. The intervention is usually

(*Continued*)

done with roadmapping; therefore, if the patient moves the head, guiding images could be lost.

Vascular access Based on a gradual continuation of an ascending path from the descending aorta, aortic arch, and cerebral arteries, the femoral artery is usually selected as the first choice for vascular access. When the right iliofemoral artery is blocked, left femoral artery access can be used. Sometimes, the right radial or brachial arteries can be used for digital substraction angiography (DSA) of the internal carotid artery and bilateral vertebral arteries. However, it is not easy to advance a guide to the cerebral arteries via the radial or brachial approach. In some rare exceptions, access by the left radial artery may be used for selective angiography of the left vertebral artery. Therefore, in interventional neurology, the radial or brachial arteries are not used on a routine basis, only in cases where the femoral approach cannot be used. Direct puncture of the common carotid artery (CCA) is a rare option when both femoral and brachial arteries are not accessible.

Table 30.1 **Thrombolysis in Cerebral Infarction to modified Treatment in Cerebral Infarction (mTICI) Scale (including 2C grade). [2, 3]**

Grade	Sub-grade	Description
0		No perfusion
1		Penetration but not perfusion. Contrast penetration exists past the initial obstruction but with minimal filling of the normal territory
2		Incomplete perfusion wherein the contrast passes the occlusion and opacifies the distal arterial bed but rate of entry or clearance from the bed is slower or incomplete when compared with non-involved territories A Antegrade reperfusion of less than half of the occluded target artery previously ischemic territory (i.e. in one major division of the middle cerebral artery [MCA] and its territory) B Some perfusion with distal branch filling of <50% of territory visualized C Near-complete perfusion except for slow flow in a few distal cortical vessels or presence of small distal cortical emboli
3		Complete perfusion with normal filling of all distal branches

Tips and Tricks

Which vascular access? If the femoral arteries are palpable, a puncture and retrograde arterial contrast injection should be made to create a “roadmap” in order to evaluate the partially or totally occluded iliac arteries. If the iliac arteries are only partially occluded, balloon angioplasty can be done quickly. However, if both iliac arteries are totally blocked (Figure 30.1), vascular access through the right radial artery should immediately be attempted. Because “time is the critical factor for viable brain tissue” in acute cerebral ischemic stroke, revascularization of chronic total occlusion in aortoiliac arteries for vascular access is not recommended. Angioplasty of the aortoiliac arteries can be performed when the cerebrovascular intervention is delayed or elective.

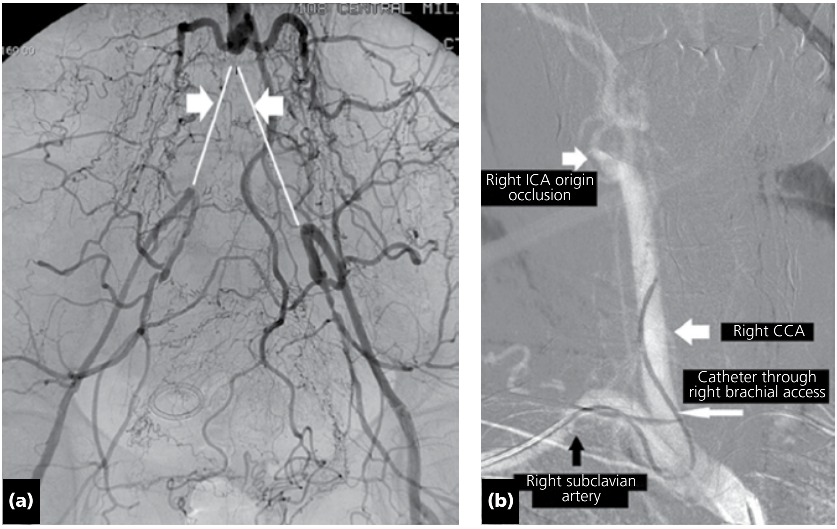

(a)
Right ICA origin occlusion
Right CCA
Catheter through right brachial access
Right subclavian artery
(b)

Figure 30.1 Vascular access. (a) Chronic occlusive lesions of bilateral external iliac arteries (white arrows and lines). (b) Vascular access through the right radial artery for the procedure. CCA = common carotid artery; ICA = internal carotid artery.

ANATOMICAL CHALLENGES

Classification of the Aortic Arch Morphology

Aortic arch morphology comprises three types: I, II, and III (Figure 30.2). The vertical distance from the origin of the brachiocephalic trunk to the top of the arch in the parasagittal "stretched-out" projection is used to differentiate the anatomy of the aortic arch. In a type I arch, this distance is <1 diameter of the left CCA. If the distance is between 1 and 2 diameters, it is a type II arch, and if it is >2 diameters, it is a type III arch. Elderly and/or hypertensive patients usually have type II or III.

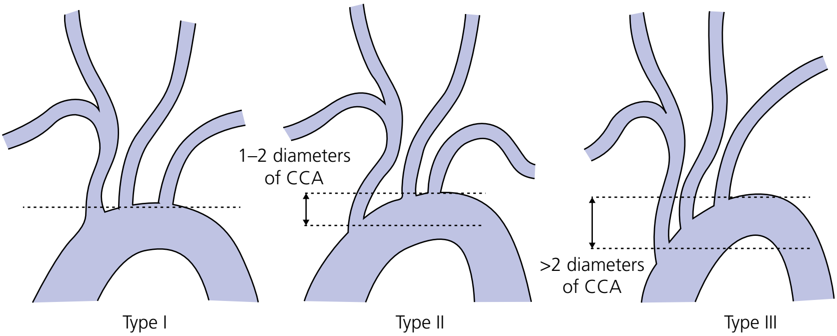

1–2 diameters of CCA
>2 diameters of CCA
Type I
Type II
Type III

Figure 30.2 Morphological classification of the aortic arch. CCA = common carotid artery.

Challenges

In aortic arch type I, the task of steering the diagnostic catheter or interventional guide into the internal carotid arteries or bilateral vertebral arteries is generally not difficult. In aortic arch type II and especially type III, it is much more difficult. The problem is the acute angle between the aortic arch and the right CCA, and especially with the right brachiocephalic artery. Therefore, it is important to evaluate the morphology of the aortic arch before the procedure in order to select successfully the appropriate catheter or guide.

NON-INVASIVE DIAGNOSTIC IMAGING

NonContrast Computed Tomography (NCCT), computed tomography angiography (CTA), multiphase CTA, Magnetic Resonance Imaging (MRI) are commonly used for calculating ASPECT score, confirming the site of the cerebral artery occlusion and collateral grade. CTA and digital subtration angiography (DSA) are used to determine the morphology of the aortic arch. DSA can also be used for roadmapping. With modern imaging technology, three-dimensional reconstructions or virtual reality images of the aortic arch can be reconstructed and its morphology can be quickly and clearly identified (Figure 30.3).

DSA for roadmapping of the aortic arch is done at the left anterior oblique (LAO) 30° angle so that the level of angulation between the aortic arch and carotid arteries is precisely visualized (Figure 30.4).

INVASIVE DIAGNOSTIC IMAGING

Diagnostic Catheter

The clinical presentation of the patient and the CTA images are used to determine the suspected culprit artery. In cases of aortic arch type I, a vertebral 45° or multipurpose catheter can easily engage the CCA or vertebral arteries. In cases of aortic arch type II or III, it is better to use diagnostic catheters with morphological consistency with the direction of the branches of the aortic arch such as the Mani, Newton, Simmons or Judkin right (JR) catheters (Figure 30.5).

When the tip of the catheter is stabilized at the proximal segment of the culprit artery, the wire is withdrawn from the catheter. Perform roadmapping as in Table 30.2.

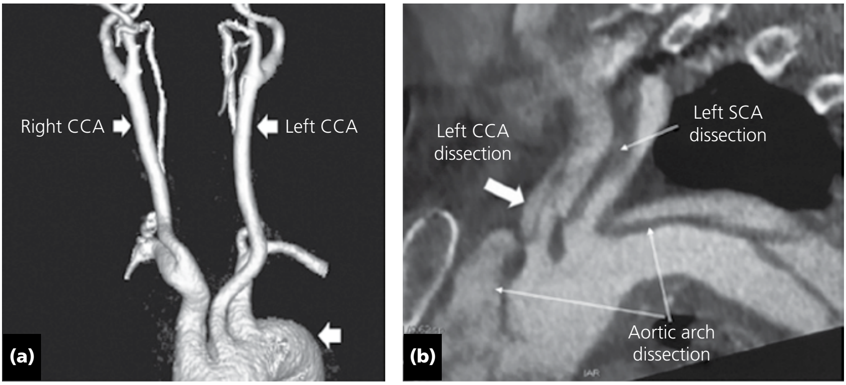


Figure 30.3 Computed tomography angiogram (CTA) of the aortic arch. (a) CT 3D reconstruction showing an aortic arch with type II morphology. (b) CTA visualizing the morphology of a type II aortic arch with type A dissection. CCA = common carotid artery; SCA = superior cerebellar artery.

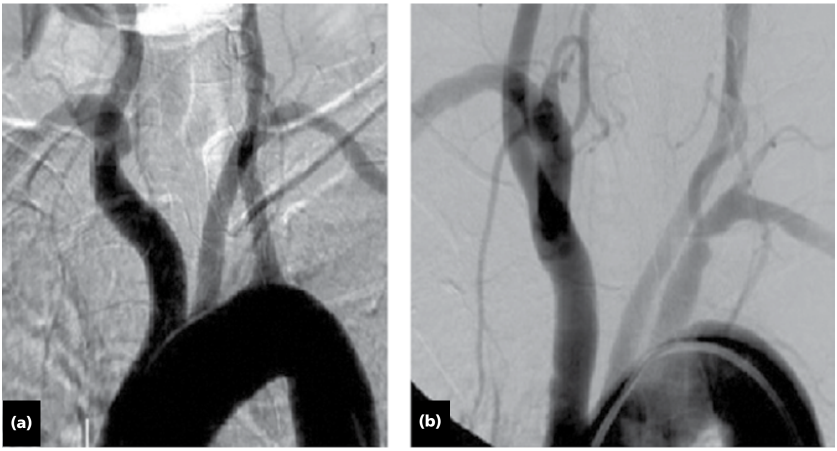


Figure 30.4 Digital subtraction angiography images of the aortic arch. (a) Aortic arch with type II morphology. (b) Type III morphology.

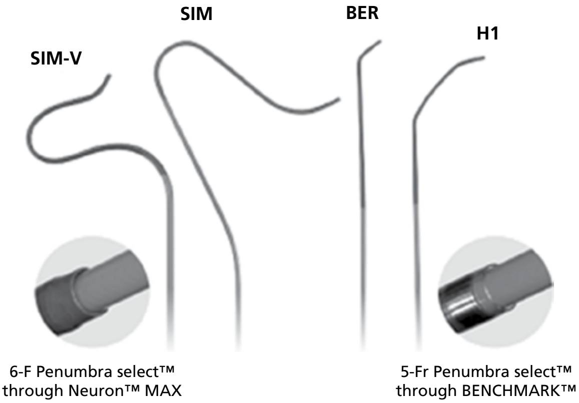


Figure 30.5 Equipment for engaging target arteries. Many 5- and 6-Fr catheters of different shape (Penumbra Select™; www.penumbrainc.com) help the advancement of the interventional guide Neuron™ MAX 088 into the carotid artery. These catheters use 0.035- or 0.038-inch wires. Other regular diagnostic catheters could do the same.

Table 30.2 **Position of the camera for roadmapping**

Artery	Position of the camera
Left vertebral artery	Anterior–posterior (AP) position
Left common carotid artery	LAO 20–30°
Right vertebral or right CCA	RAO 20–30°

CCA = common carotid artery; LAO = left anterior oblique; RAO = right anterior oblique.

If the CTA images and roadmapping show that the internal carotid artery is occluded in its cervical segment, it is necessary to advance the tip of the catheter in the CCA. If the occluded site is intracranial or at the base of the skull, advance the catheter along the wire into the base of the internal carotid artery. For the bilateral vertebral arteries, the tip of the catheter can be advanced 3–4 cm deep into the artery.

Tips and Tricks

If the carotid or vertebral artery has a lesion When stenosis at the proximal segment of the carotid or vertebral arteries is suspected, do not advance the catheter through the stenotic lesion because there is a greater risk of dissection and vascular occlusion. Furthermore, it is necessary to evaluate the levels of stenosis by taking DSA images proximal to the stenotic site.

CLASSIFICATION OF LESIONS

In general, the cerebral circulation can be viewed as a two-part system: (1) the internal carotid arteries (i.e. anterior circulation), and (2) the vertebrobasilar artery (i.e. posterior circulation). Ischemic stroke can occur in one of these two circulations, or even both. The first underlying pathology is the atherosclerotic lesions that cause significant stenosis at the proximal segment of the carotid or vertebral arteries (Figures 30.6 and 30.7). This can result in the formation of thrombi that migrate in an antegrade fashion and cause occlusion in large intracranial vessels. The second pathology is the stenotic plaque in the intracranial arteries that causes in situ thrombus. The third pathology is the occlusion of an artery by emboli from the heart or aorta. The final event is a large-vessel acute ischemic stroke.

Multisegmental Thrombosis

When thrombus formation occurs at the proximal segment of the artery, one part of the thrombus may move distally and the other part remain at the original site. This creates a multisegmental or tandem lesion (Figure 30.8).

Atherosclerotic Plaque-induced Thrombus in the Intracranial Arteries

Atherosclerotic plaques causing stenosis of intracranial arteries are the cause of thrombus formation and stroke. These stenoses can be corrected by balloon angioplasty and intracranial stenting (Figures 30.9 and 30.10)

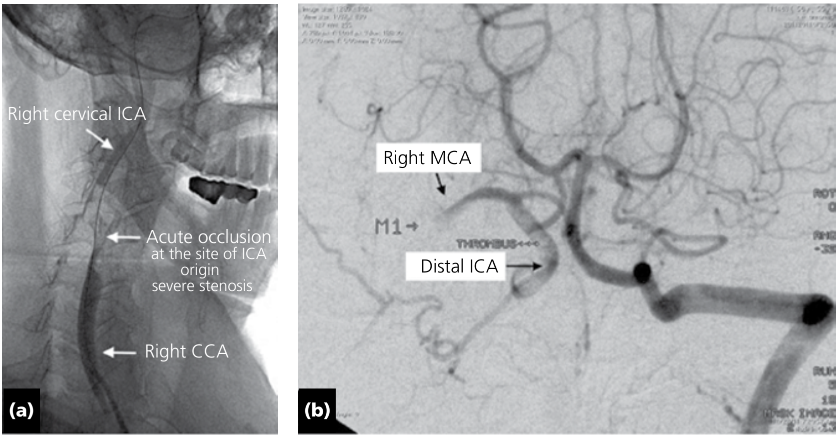


Figure 30.6 High-grade stenosis of the internal carotid artery (ICA) with tandem thrombi: in situ thrombus and at the distal ICA through right middle M1 branch. (a) Severe stenosis of right ICA occluded due to acute thrombus (middle arrow). (b) The thrombus at the end of the ICA to right middle M1 (arrow). CCA = common carotid artery; MCA = middle cerebral artery.

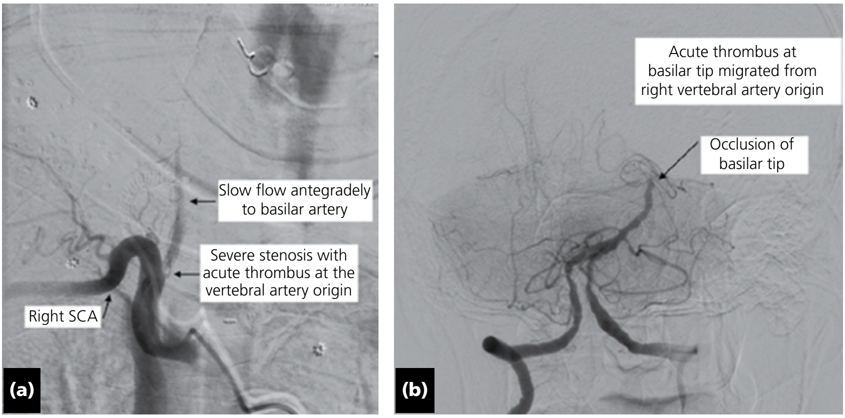

Slow flow antegradely to basilar artery
Severe stenosis with acute thrombus at the vertebral artery origin
Right SCA
(a)
Acute thrombus at basilar tip migrated from right vertebral artery origin
Occlusion of basilar tip
(b)

Figure 30.7 Stenosis of the right vertebral artery with thrombus at the basilar artery. (a) Severe stenosis at the root of the right vertebral artery, and (b) a basilar tip thrombus. SCA, superior cerebellar artery.

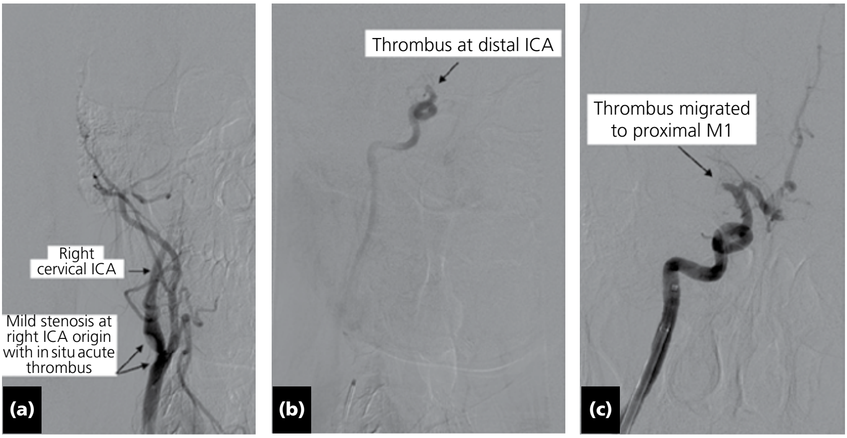

Right cervical ICA
Mild stenosis at right ICA origin with in situ acute thrombus
(a)
Thrombus at distal ICA
(b)
Thrombus migrated to proximal M1
(c)

Figure 30.8 A multisegmental thrombus is seen at the site of the atherosclerotic plaque at both the proximal segment (a) and the end (b) of the right internal carotid artery (ICA). The image of the thrombus is better visualized at the beginning of M1 (c). SCA = superior cerebellar artery.

GAME PLAN

Once the diagnostic imaging is done, it is important to observe and look for details of the extra- and intracranial arteries using either MRA or CTA before the interventional procedure and DSA during the procedure in order to select appropriate strategies. The goal of treatment in a patient with extracranial stenosis is to open a conduit through the stenosis at the proximal segment of the internal carotid or vertebral arteries or perform angioplasty or stenting in order to advance the guide upward in order to remove the thrombus. Currently, there are two popular techniques to revascularize cerebral arteries in large-vessel ischemic stroke: thrombus removal with stent-like devices, and thrombus aspiration with catheters. Once the thrombus is removed, subsequent angioplasty or stenting can be considered.

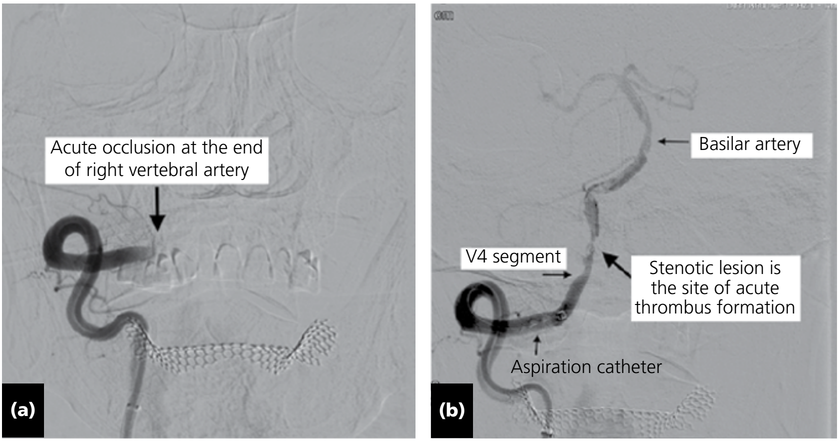

Acute occlusion at the end of right vertebral artery
(a)
Basilar artery
V4 segment
Stenotic lesion is the site of acute thrombus formation
Aspiration catheter
(b)

Figure 30.9 Severe stenosis of the vertebral arteries causing thrombus and basilar artery infarction. (a) Occlusion at the end of the right vertebral artery – V4 due to thrombus. (b) After thrombus aspiration, a stenotic lesion could be identified at V4.

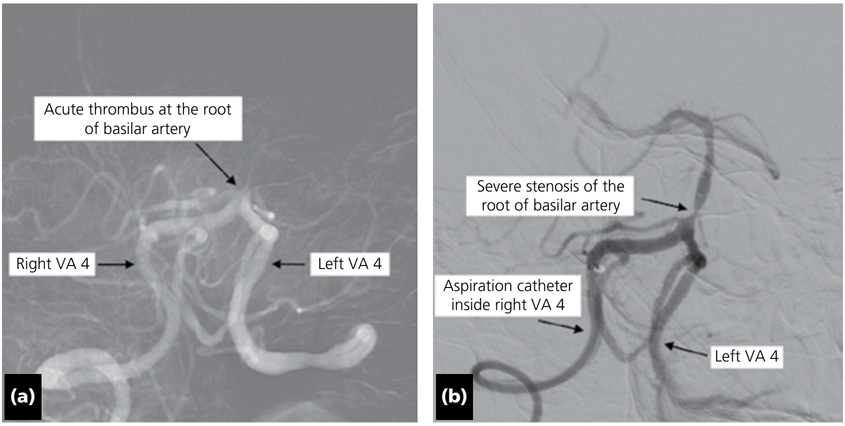

Acute thrombus at the root of basilar artery
Right VA 4
Left VA 4
(a)
Severe stenosis of the root of basilar artery
Aspiration catheter inside right VA 4
Left VA 4
(b)

Figure 30.10 Thrombus at the basilar artery. (a) Infarction due to thrombus at the root of the basilar artery. (b) Severe stenosis of the root of the basilar artery is well visualized after thrombus aspiration. It is very difficult to revascularize cerebral arteries by only performing thrombus aspiration at sites of stenosis. VA = vertebral artery.

Real-time Actions: Interventions of Lesions Proximal to the Thrombus

Exchanging the diagnostic catheter with a guide In order to approach the lesion most rapidly, after diagnostic angiography move the diagnostic catheter into the CCA or the proximal segment of the vertebral artery for roadmapping. An exchange wire 0.035-inch tip 45°, soft or standard, is used to replace the diagnostic catheter with the 8-Fr guide (Corail, Neuron MAX 088). The guide is connected to the continuous infusion line of heparin via the side arm of the Y connector.

GUIDE

Usually the selected guide is 80 cm long; in patients taller than 170 cm and with aortic arch type III, a 90-cm guide is needed. The guide needs to be placed in a stable position at the proximal segment of the index artery. However, the cervical segment of the carotid artery can easily spasm or become dissected. This can happen during maneuvering of the diagnostic catheter and the 8-Fr interventional guide, especially when the extracranial carotid artery is looping or angulated.

Tips and Tricks

Precautions when manipulating devices It is very important to be cautious when advancing any device (microwires, microcatheters, aspiration catheters, stents, etc.) In general, the operator should:

1. Manipulate all the devices and monitor their movement with roadmapping.
2. Stop advancing when resistance is met.
3. Stop withdrawing any device, especially a stent, whenever the device becomes entrapped, caught, or stuck.
4. Use a balloon-mounted guide to create reverse blood flow from the cerebral artery to the catheter when using the stent retriever for thrombectomy.

****Monitoring the tip of the wire** It is important to monitor the position of the wire at the base of the skull under fluoroscopy in order to avoid prolapse of the wire out of the target artery.

****Patient's position** During the process of exchanging catheters or devices, it is critical to keep the head of the patient immobile for roadmapping.

****Catheters and wires** After the guide moves into the aortic arch, slow down all maneuvers. This is the hallmark of a skilled operator. In order to avoid prolapse of the exchange wire, it is necessary to advance the catheter gently and rotate it counterclockwise while the assistant holds and stabilizes the exchange wire. When there is resistance and the wire is pulled downward, it is necessary to exchange the wire for a Glidewire tip 45°, soft and standard (or stiff), to provide better support and to further straighten the angulation between the carotid artery and the aortic arch. After advancing the tip of the guide into the target artery, check for free blood flow at the tip of the guide, then finally remove all wires.

ADVANCING THE GUIDE INTO THE CAROTID ARTERY

In general, a coaxial catheter system with a 260-cm hydrophilic wire is used to advance the guide or catheter into the right or left internal carotid artery. The typical device components include: 8-Fr femoral sheath, 5-Fr Mani or Simmons 2 diagnostic catheter, Glidewire 0.035-inch hydrophilic wire (standard and stiff/150 and 260 cm), Neuron MAX 088 guide (long-sheath) (Figure 30.11).

Procedure

Under the guidance of DSA roadmapping, move the wire through the diagnostic catheter into the brachiocephalic artery. Withdraw the 150-cm short wire and replace it with the 260-cm-long wire (standard or stiff). Withdraw the diagnostic catheter, and then slide the Neuron MAX guide into the aortic arch. Next, withdraw and replace its core dilator with the 5-Fr diagnostic catheter, which is now used as a small coaxial catheter along with the wire to slide the Neuron MAX guide into the internal carotid arteries (Figure 30.12).

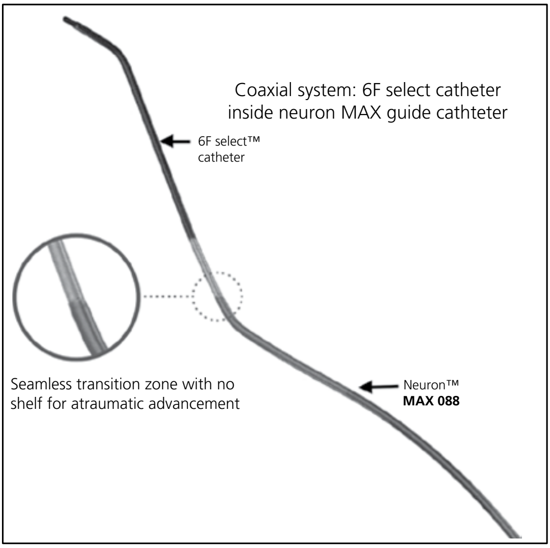

Coaxial system: 6F select catheter inside neuron MAX guide cathteter
6F select™ catheter
Seamless transition zone with no shelf for atraumatic advancement
Neuron™ **MAX 088**

Figure 30.11 Devices used to advance the Neuron MAX guide into the internal carotid arteries. Source: Penumbra / www.penumbrainc.com / Accessed on May 23, 2025.

Stenosis of the Middle Cerebral Artery

When severe stenosis is present in the middle cerebral artery (MCA), thrombus aspiration may be attempted (Figure 30.13a). In this situation, intracranial balloon angioplasty needs to be performed first (Figure 30.13b) to widen the lesion, and, if this is ineffective, intracranial stenting (Figure 30.13c). In the case illustrated, stenting was performed successfully.

Tips and Tricks

Advancing the catheter and guide in a tortuous cervical carotid artery In cases where the cervical segment of the carotid artery is angulated or serpentine, it is necessary to choose a catheter 90 cm long. Park the tip of the catheter immediately proximal to the first angulated site in order to avoid spasm or dissection of the arterial wall. Perform roadmapping from the tip of the catheter at the ipsilateral oblique 20–30° position for the internal carotid artery, and at the AP position for the basilar artery.

After advancing the Penumbra coaxial aspiration system or Rebar 18 microcatheter along with the 0.014–0.016-inch microwire under the guidance of roadmapping, it is necessary to assess the supportive ability of the guide so that interventional devices can be advanced near the thrombus. The operator must also evaluate the straightened segment of the internal carotid artery to decide whether to maintain the catheter in place or advance it higher. At that time, the catheter as well as the wires inside it will support further advancement of the guide.

If there is spasm of the carotid artery, withdraw the guide to below the site of vasospasm. Add a calcium channel blocker into the continuous fusion line via the guide (nimodipine 2–3 mg in 500 mL normal saline will help to control spasm).

Advancing devices across the petrous segment to the intracranial area The petrous segment of the internal carotid artery (located inside the temporal bone) is best seen on the lateral view. However, in most cases, an ipsilateral oblique 30–40° view is most useful. Furthermore, the tip of the microwire is crucial. It must be preshaped in a "wide S". With the microwire tip in an "S" shape, it should be easy to steer the wire along the curves of the internal carotid artery in the

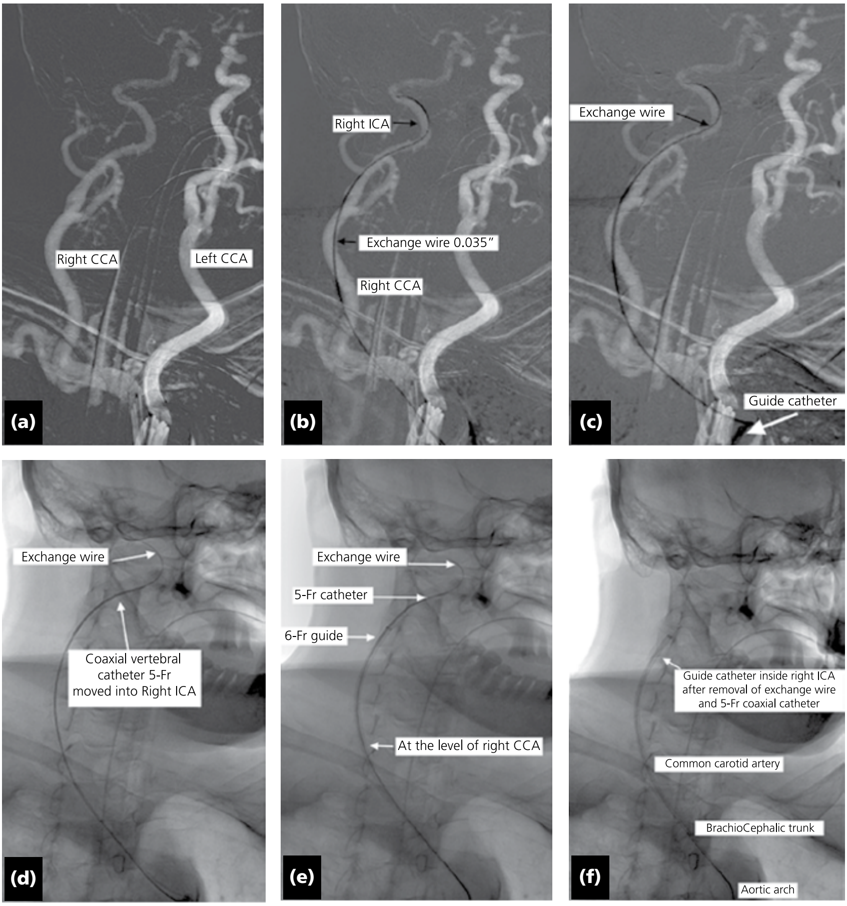

Right CCA
Left CCA
(a)
Right ICA
Exchange wire 0.035″
Right CCA
(b)
Exchange wire
Guide catheter
(c)
Exchange wire
Coaxial vertebral catheter 5-Fr moved into Right ICA
(d)
Exchange wire
5-Fr catheter
6-Fr guide
At the level of right CCA
(e)
Guide catheter inside right ICA after removal of exchange wire and 5-Fr coaxial catheter
Common carotid artery
BrachioCephalic trunk
Aortic arch
(f)

Figure 30.12 Advancement of a coaxial system into internal carotid arteries (ICA). (a) Roadmapping through a 5-Fr Mani or Simmons type diagnostic catheter. (b) Exchange wire 0.035-inch × 260 cm pushed through a 5-Fr catheter upward into the right ICA. (c) Keep the exchange wire in situ while removing the diagnostic catheter followed by advancing the 6-Fr guide catheter up to the aortic arch (white arrow). (d) Use a 5- or 6-Fr select catheter to push the inside guide catheter upward into the common carotid artery (CCA) then the ICA to make a good backup for the guide catheter moving up. (e) Slide upward the guide catheter to the cervical ICA while firmly keeping the exchange wire and 5-Fr catheter inside. (f) Remove the wire and 5-Fr catheter, keeping the guide catheter in the ICA, ready to deploy devices into the ICA.

petrous segment, and especially to overcome the carotid syphon. In contrast, at the basilar skull, it is necessary to note the unexpected sites into which the microwire may prolapse inadvertently. These are the ophthalmic artery, posterior communicating artery, and choroidal artery.

WARNING

Some patients with acute ischemic stroke may have unruptured aneurysms at the circle of Willis. This is a big trap because the microwire can perforate the aneurysm and cause subarachnoid hemorrhage. This complication is highly dangerous and it may not be possible to stop the bleeding.

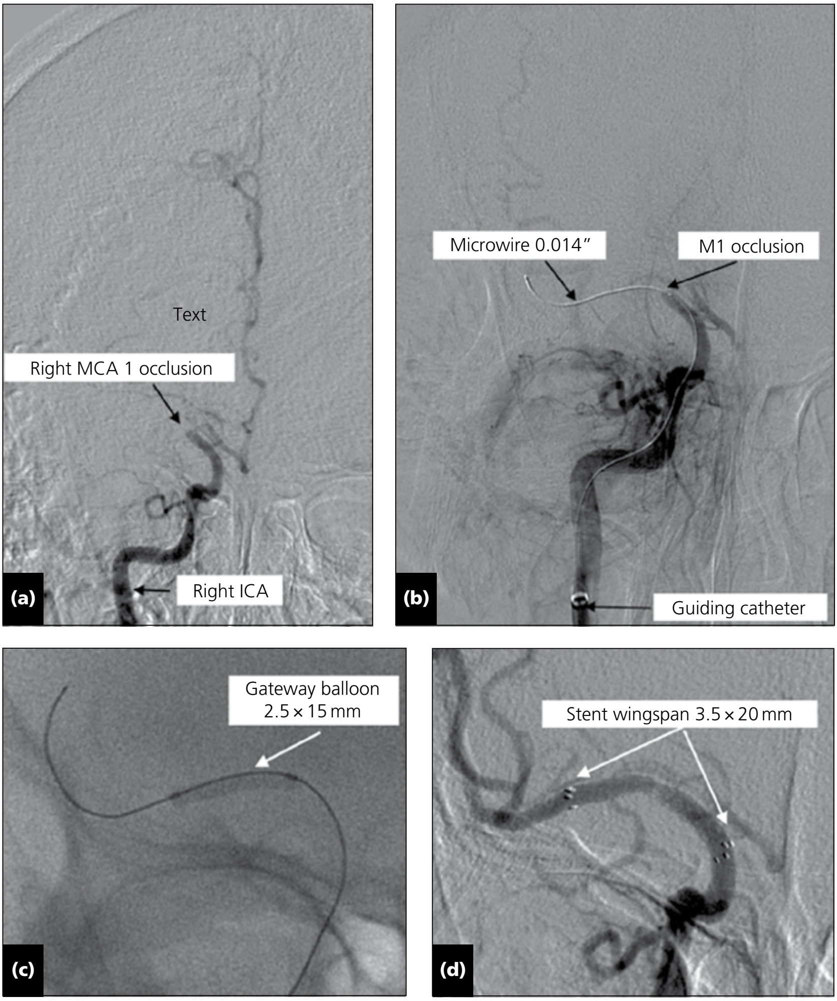

Text
Right MCA 1 occlusion
Right ICA
(a)
Microwire 0.014″
M1 occlusion
Guiding catheter
(b)
Gateway balloon
2.5 × 15 mm
(c)
Stent wingspan 3.5 × 20 mm
(d)

Figure 30.13 Severe stenosis of middle cerebral artery (MCA) causing thrombus and cerebral infarction. (a) Occlusion of the initial right M1 due to thrombus. (b) Moving the guidewire through the stenosis. (c) Performing balloon angioplasty (upper panel) and stenting intracranially (lower panel). ICA = internal carotid artery.

REMOVAL OF CLOTS

Thrombus Removal with Stent-like Devices

The most popular device is the Solitaire™ FR stent (Figure 30.14). Other devices are the Revive IC Intermediate catheter and the Trevo XP Stentriever.

Technique of Thrombus Removal with Solitaire FR

(Figures 30.15 and 30.16)

The essential components for thrombus removal are: an 8-Fr femoral sheath, an 8-Fr balloon-mounted Cello™ guide or Corail, a 6-Fr FargoMAX or Envoy® catheter, 0.014–0.016-inch cerebral microwires, 18-mm microcatheter, and 4.0 × 20 mm, 4.0 × 40 mm Solitaire FR stent.

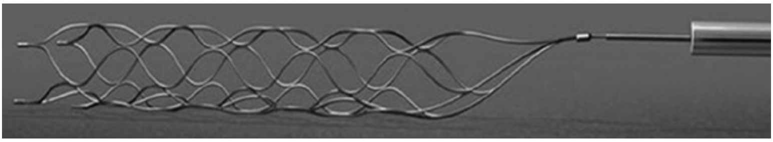
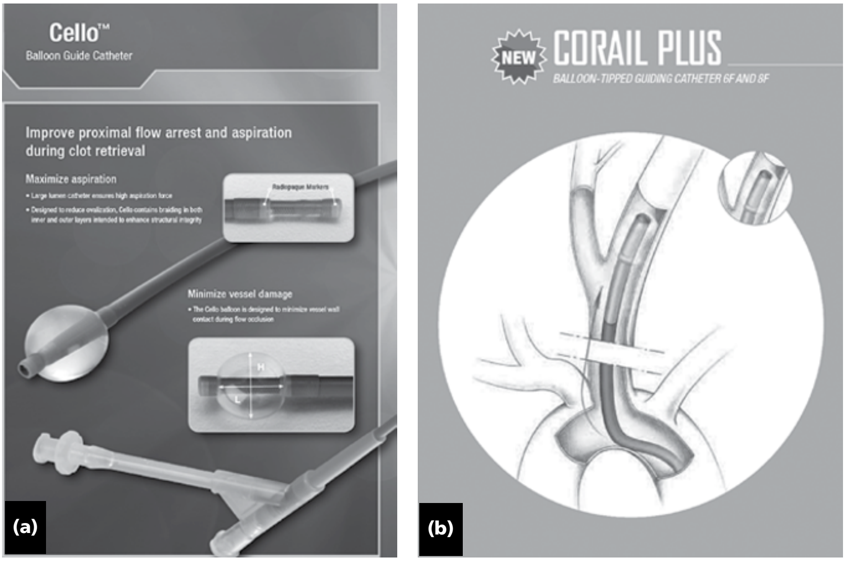


Figure 30.14 SolitaireFR stent.



Cello™

Balloon Guide Catheter

Improve proximal flow arrest and aspiration during clot retrieval

Maximize aspiration

- Large lumen catheter ensures high aspiration force
- Designed to reduce ovalization, Cello contains braiding in both inner and outer layers intended to enhance structural integrity

Minimize vessel damage

- The Cello balloon is designed to minimize vessel wall contact during flow occlusion

NEW CORAIL PLUS

BALLOON-TIPPED GUIDING CATHETER 6F AND 8F

Figure 30.15 Balloon guiding catheters. (a) Cello™ balloon guiding catheter. (b) Corail balloon guiding catheter.

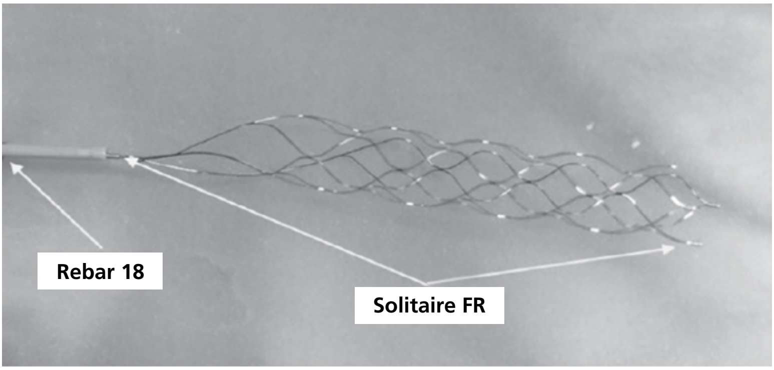


Figure 30.16 Rebar18 microcatheter and Solitaire FR stent after deployment.

The use of DSA is the best way is to advance the 5-Fr diagnostic catheter along with the 0.035-inch hydrophilic wire into the proximal segment of the culprit artery. The affected artery is previously confirmed by clinical examination and CTA; further DSA images are obtained at 3 frames/s and at the AP cranial 15–20° (for the internal carotid artery) or AP caudal 10–15°

(for the basilar artery), and lateral 90° (for both) positions. Arterial, capillary, and venous flow are used to assess the leptomeningeal collateral circulation to the ischemic territory.

Advance and position the guide (Figures 30.17 and 30.18) Due to the stiffness and "straight" form of the catheter, it is difficult to advance the guide directly into the aortic arch as compared to diagnostic catheters, especially in patients with aortic arch types II and III. Therefore, after diagnostic angiography, it is better to withdraw the catheter into the CCA, move the C-arm to the oblique angle of 30° (same side), and then inject contrast to take roadmap images of the common, external, and internal carotid arteries. Steer the hydrophilic wire (0.035-inch, 260 cm long, soft head of 45°, standard) into the external carotid artery. (Beware: it is not recommended to leave the wire in the internal carotid artery due to the risk of perforation and dissection.) Withdraw the diagnostic catheter, leaving the wire in place, and then continue monitoring as well as keeping the wire in the external carotid artery. Next, slide the balloon-mounted 8-Fr Corail or Cello guide catheter along the wire into the CCA. After that, withdraw the wire from the external carotid artery and steer it into the internal carotid artery in order to advance the guide into the internal carotid artery. Then withdraw the wire and begin the continuous infusion of heparin (5000 IU in 1 L normal saline) into the guide at a rate of about 40–60 gouttes/min.

Localization of the occlusion and opening the stent at the thrombosis site The operator uses roadmapping images to guide maneuvers, advancing the 0.014-inch microguidewire along with the 18 microcatheter through the occluded segment into the artery lumen distal to the occlusion site (Figure 30.18). Next, the microguidewire is withdrawn, while the Solitaire stent is advanced into the peripheral tip of the microcatheter until the length of the stent covers all of the thrombus. When the stent is maintained in place and the microcatheter pulled back, the stent will automatically fully expand into the arterial wall and hold the thrombus inside. The arterial flow will be restored immediately. The stent should remain open for about 5 min.

Thrombus Aspiration (Figure 30.18)

Inflate the balloon at the tip of the guide to obstruct the arterial flow. Then use the 50 mL syringe to aspirate from the guide via the side arm of the Y connector to create reversed flow from the cerebral arteries into the guide, at the same time withdrawing both the stent and thrombus out of the cerebral artery into the guide lumen (Figure 30.19).

After withdrawing the stents from the guide, it is important to double-check for the presence of remaining thrombus in the artery (Figure 30.20). Repeat the maneuvers if there is still thrombus remaining inside the cerebral arterial lumen. Usually only one pass is needed to remove all thrombi. However, in some cases, the process may need to be repeated two or three times in order to remove all the clots.

Confronting the Challenges

When it is impossible to remove the thrombus When it turns out to be impossible to remove the thrombus using the stent, there are three further options: (1) aspiration via the Penumbra catheter, (2) combination of both devices with the Solumbra SAVE, ARST techniques, or (3) selective arterial thrombolysis via the catheter (especially when there are many small thrombi that migrate distally).

Thrombus Aspiration with Catheter

The most commonly used aspiration catheter is the Penumbra aspiration catheter system (Figure 30.21). An advantage of this device is that it does not need to use a balloon-mounted guide. The components are: an 8-Fr femoral sheath, Neuron MAX 088 guide, the coaxial aspiration system 3MAX, ACE 64-68, Jet7, RED72, and a 0.014-inch microwire.

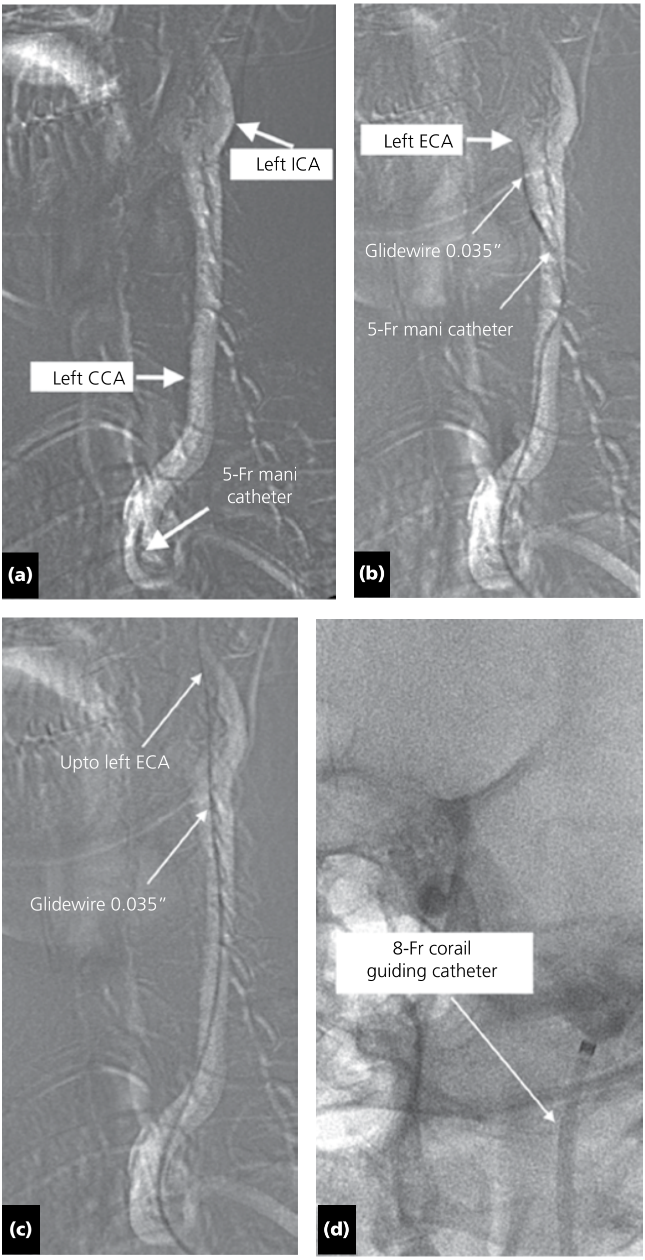

Left ICA
Left CCA
5-Fr mani catheter
(a)
Left ECA
Glidewire 0.035″
5-Fr mani catheter
(b)
Upto left ECA
Glidewire 0.035″
(c)
8-Fr corail guiding catheter
(d)

Figure 30.17 Advancing the guide. The operator should advance the 8-Fr balloon-mounted Corail guide into the left internal carotid artery (ICA). (a) Diagnostic Mani 5-Fr diagnostic catheter performing roadmapping of the left common carotid artery (CCA). (b) Advancing the diagnostic catheter along the 0.035-inch wire into the distal left CCA. (c) Using a 0.035-inch 260-cm exchange wire in order to withdraw the diagnostic catheter out of the artery lumen. (d) The balloon-mounted 8-Fr Corail guide is advanced into the left internal carotid artery along the exchange wire followed by removal of the wire. ECA = external carotid artery.

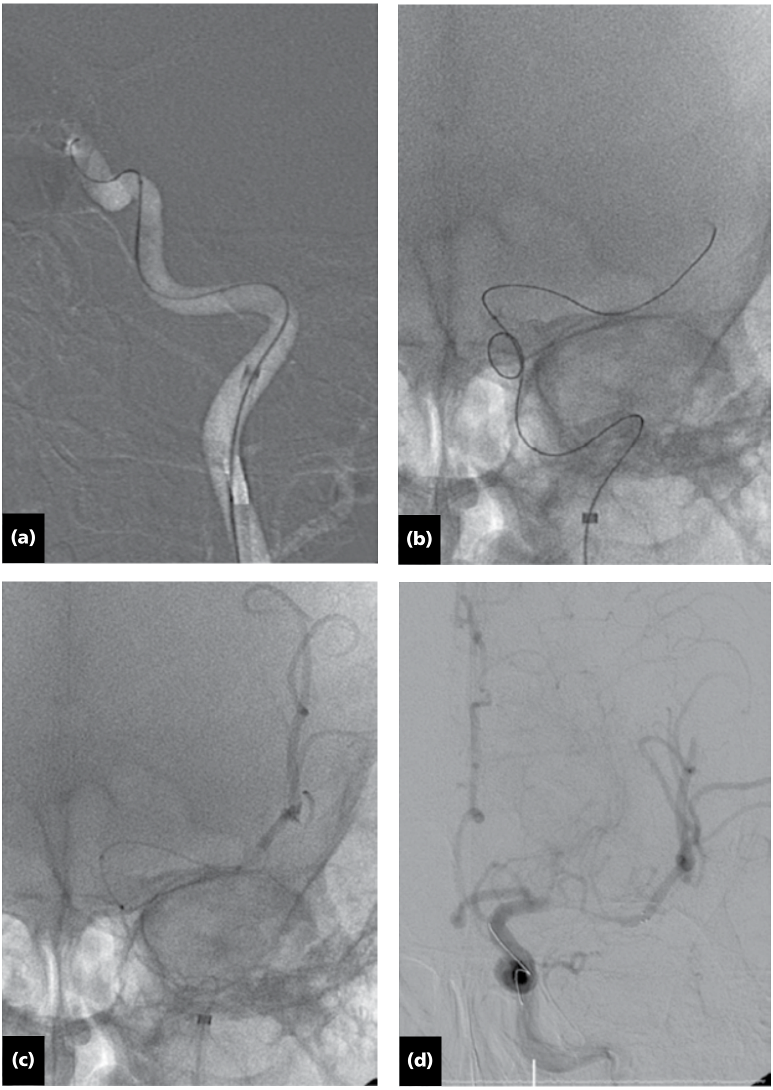


Figure 30.18 The process of removing thrombus from the middle cerebral artery (MCA) with the Solitaire FR stent. (a) Following the guidance of roadmapping, advance the 0.014-inch microwire along with the Rebar 18 microcatheter from the guide into the terminal segment of the internal carotid artery. (b) After repeat roadmapping focusing on the occluded territory of the MCA, advance the microwire through the thrombus into the arterial lumen of segments M2–3. (c) Slide the Rebar 18 microcatheter along the wire to the initial segment of M2. After this, withdraw the wire and inject 1 mL of contrast through this microcatheter with the 10-mL syringe to evaluate flow distal to the occlusion site. (d) Advance the Solitaire FR stent into the Rebar 18 microcatheter, then stop at the initial segment of M2. Deploy the stent by withdrawing the microcatheter while holding the delivery wire of the stent in place. After the stent opens, the arterial flow will be restored.

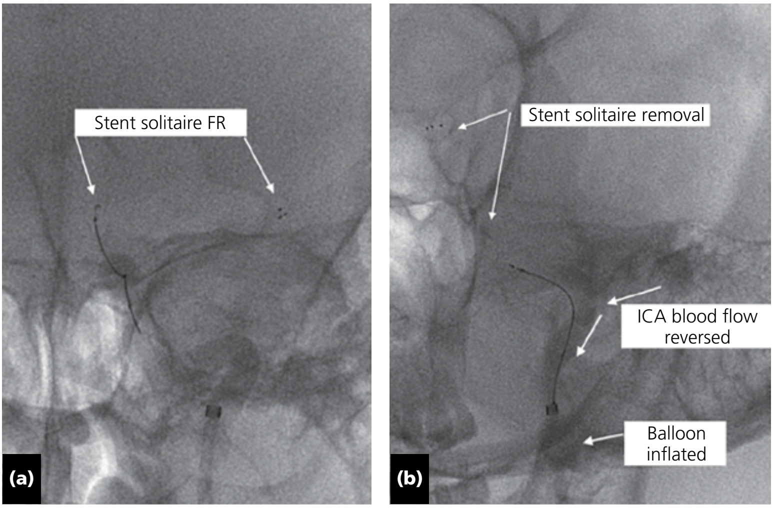


Figure 30.19 (a) After 5 min, inflate the balloon at the tip of the guide to obstruct the arterial flow, then create negative pressure by aspirating with a 50-mL syringe via the side arm of the Y connector of the guide. (b) At the same time, gradually withdraw both the Solitaire FR stent and Rebar 18 microcatheter into the lumen of the 8-Fr Corail. FR, flow restoration; ICA, internal carotid artery.

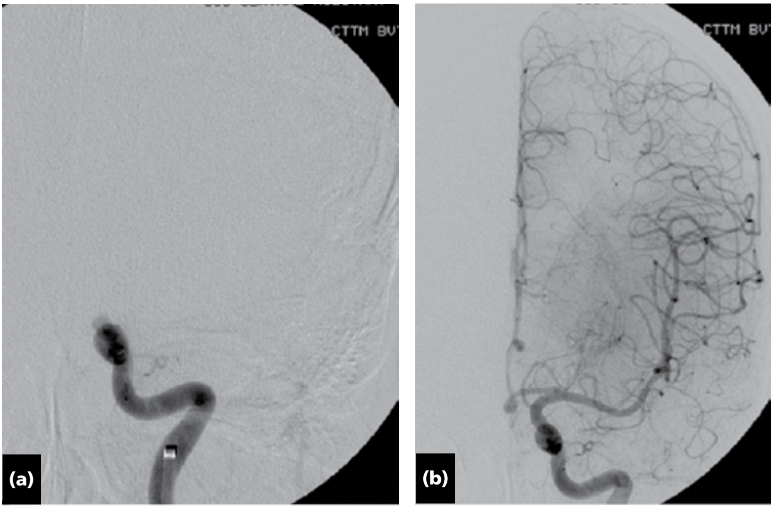


Figure 30.20 Digital subtraction angiography images (a) before and (b) after thrombus removal by the Solitaire FR stent. FR, flow restoration.

Procedure After diagnostic DSA has been performed, the diagnostic catheter is replaced with the guide via the 0.035-inch 260-cm wire. Connect the side arm of the Y connector to the continuous heparin infusion. Using roadmapping, the coaxial system 3MAX, RED72, and microwire are advanced through the guide into the occluded site of the artery. When approaching the occluded site, hold the wire and the 3MAX microcatheter

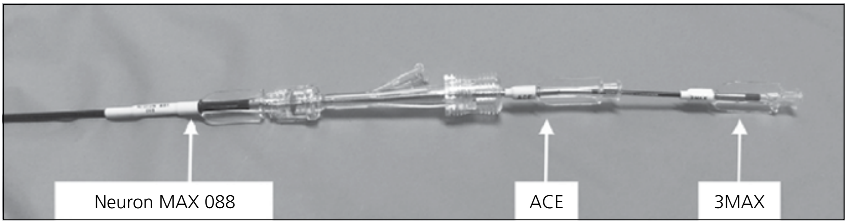


Figure 30.21 A coaxial system includes: a Neuron MAX 088guide, ACE 64 aspiration catheter, aspiration microcatheter inside 3MAX to provide support for the ACE 64 to ascend, and innermost (not shown) the 0.014- or 0.016-inch wire.

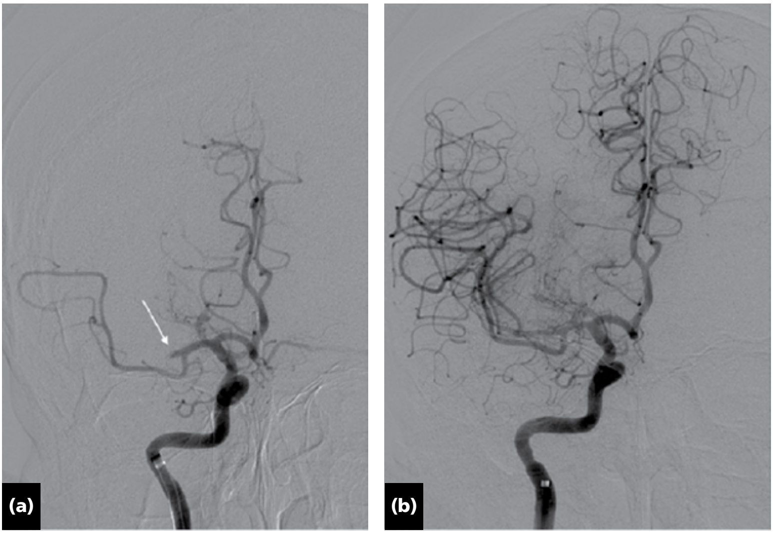


Figure 30.22 Digital subtraction angiography images (a) before and (b) after thrombus aspiration by the ADAPT Penumbra technique. The occlusion site is clearly shown in (a) (arrow).

while sliding the RED72 catheter until its tip approaches the thrombus. Connect the aspiration line (with negative aspiration pressure) to the center tip of the RED72 catheter, and maintain a negative pressure of 15–20 mmHg for 1–2 min. Next, withdraw the RED72 catheter gently through the lumen of the guide to outside while maintaining negative pressure. The thrombus can be kept inside the lumen of the RED72 or aspirated into the container (Figure 30.21 and Figure 30.22). Finally, double-check for remaining thrombi with angiography via the guide. If fragments of thrombi are still present, the process needs to be repeated.

EMBOLI FROM THE HEART

In patients with persistent atrial fibrillation (AF), with or without mitral valve diseases, or patients with subacute bacterial endocarditis (SBE) with vegetations, thrombi or septic emboli could move to the cerebral circulation (Figure 30.23) causing acute occlusion and cerebral infarction. In these cases, the clinical condition is refered to as "cardioembolic stroke".

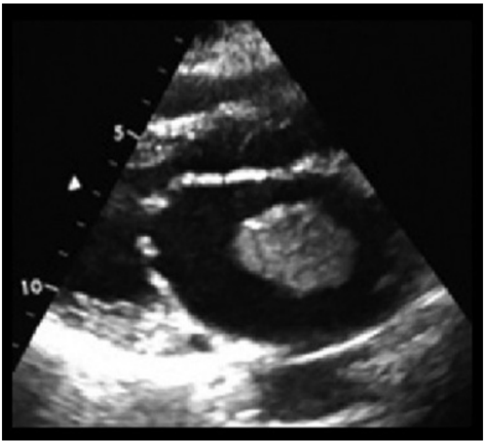


Figure 30.23 Ultrasound of large thrombus in the left atrium in a patient with atrial fibrillation and mitral valve stenosis.

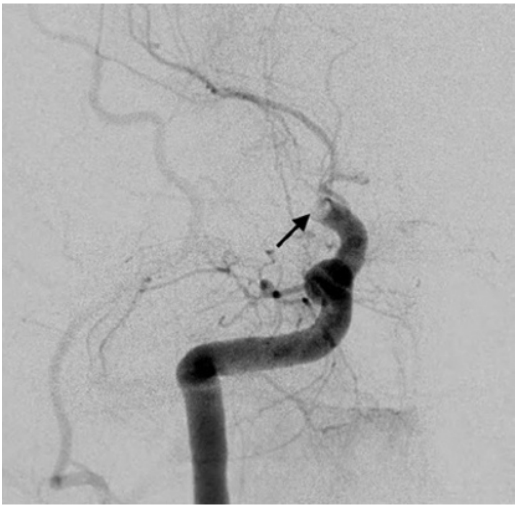


Figure 30.24 Large embolus from the heart. An embolus from the heart (arrow) is often large and very hard because it is well organized, and is impossible to remove from the cerebral arteries.

The histologic characteristics of emboli in cardioembolic stroke are usually old, dark-gray, solid, or very hard, well-organized thrombi. In some cases, it is impossible to remove the embolus from the cerebral artery (Figure 30.24), even after successfully approaching the embolus with mechanical devices.

Placing a stent to compress the embolus into the arterial wall turns out to be ineffective (Figure 30.25). This is because intracranial stents are self-expandable types, not opened and expanded by a balloon. Therefore, the centrifugal expanding force of the stent is not strong enough to compress the embolus into the arterial wall.

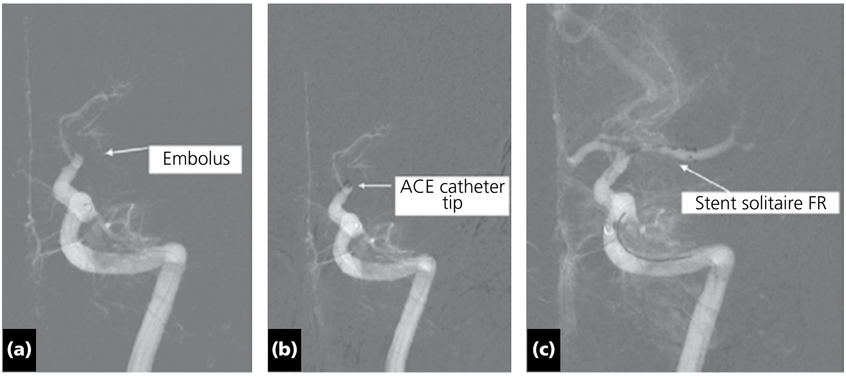


Figure 30.25 (a) An embolus from the heart valve of a 22-year-old male patient with subacute bacterial endocarditis, causing an occlusion at the terminal segment of the left internal carotid artery. (b) Vacuum aspiration by ACE® 64. (c) Removal by the Solitaire stent was ineffective. FR, flow restoration.

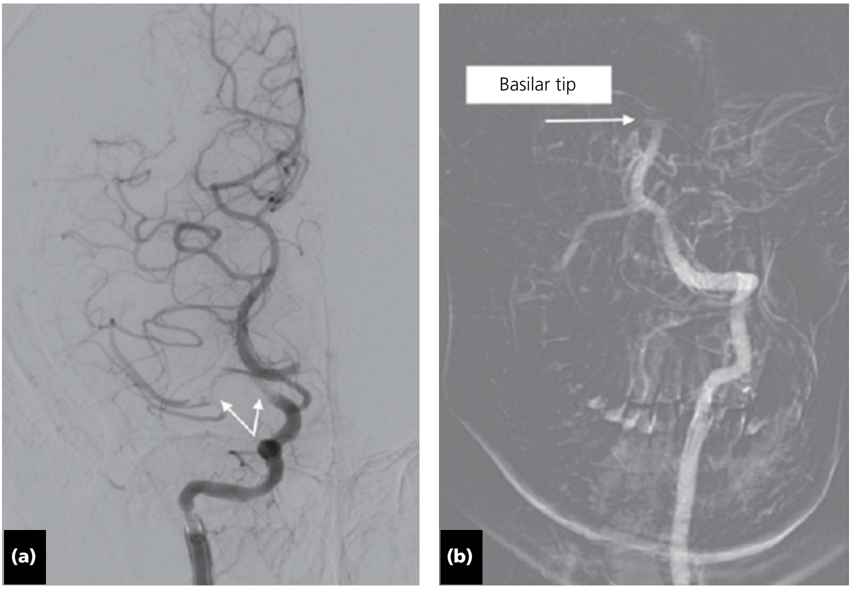


Figure 30.26 Many branches of the cerebral arteries are occluded by multiple emboli that have migrated from the heart. (a) Embolus at the end of the right internal carotid artery and M1 (arrows). (b) Embolus at the basilar tip.

Emboli moving from the heart to the brain can cause occlusion of one or two branches of the cerebral arteries (Figure 30.26), either of the bilateral internal carotid arteries, or one branch of the internal carotid artery and one vertebral artery. Thus, CTA or MRA is very useful for performing a general assessment of cerebral arterial occlusion lesions before any revascularization procedure.

MANEUVERS TO MOBILIZE THE EMBOLUS IN INTERVENTION

Mobilizing the embolus into either the distal part of an occluded arterial branch or the new branch is a complicated maneuver in revascularization of large-vessel acute ischemic stroke. When mechanical devices approach the embolus, forces are created to break down and detach the embolus. After withdrawing both devices and the embolus from the artery, there remains the risk of smaller segments from this embolus moving via normal blood flow into the peripheral branches of the artery, generating distal occlusions (Figure 30.27).

When withdrawing devices along with the embolus from the MCA into the guide, a segment of the embolus could peel off and move to the anterior cerebral artery (ACA), causing an occlusion of this artery, especially at the A2 or A3 segment. The angulation between the A1 segment of the ACA and the terminal segment of the internal carotid artery is usually an acute angle of less than 60° (Figure 30.28); therefore, advancing mechanical devices into the ACA is a big challenge.

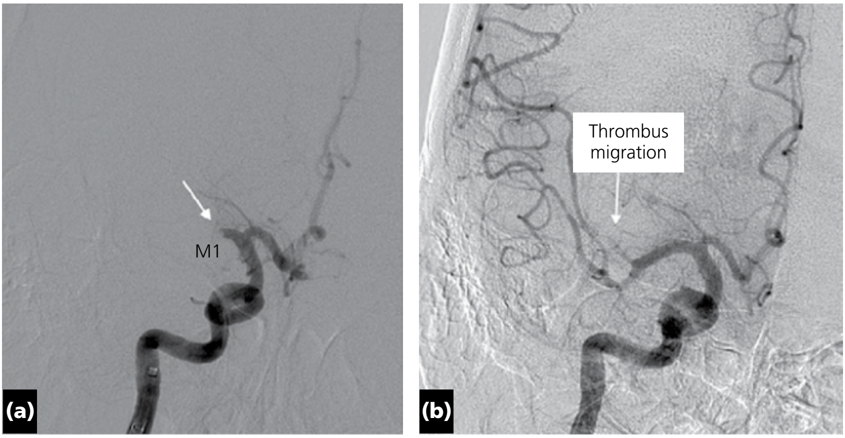


Figure 30.27 Mobilizing the embolus (arrow) from (a) M1 distally to (b) M2 in an embolus aspiration procedure in order to revascularize the cerebral arteries.

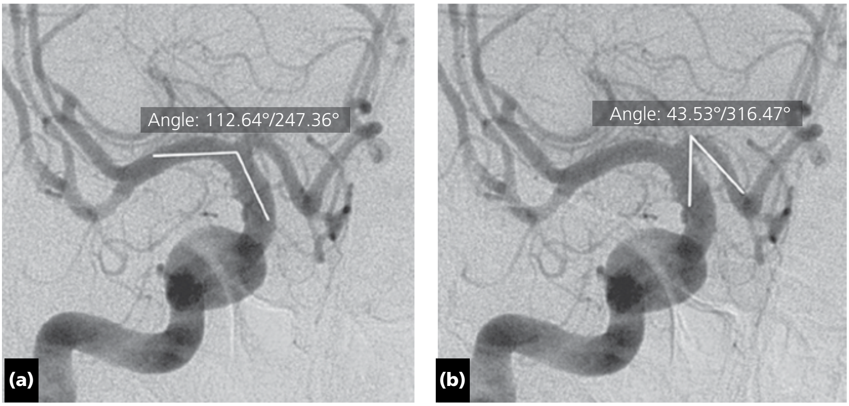


Figure 30.28 Angulation between the terminal of the internal carotid artery with (a) the M1 segment, larger than 90° and (b) the A1 segment, often acute and smaller than 60°.

TECHNICAL TIPS

How to Do it Safer or Faster

For beginners or intermediate level operators

- Advancing devices in cerebral arteries and approaching thrombus
- Removing thrombus
- Avoiding distal migration into the non-infarcted territories
- Avoiding thrombus reinjected into cerebral artery from guiding catheter

Trouble-shooting Tricks (How To Get Out of Trouble)

For the beginners or intermediate level operators

- High-grade stenosis of internal carotid and vertebral arteries
- Looping or kinking of vertebral arteries
- Spasm and dissection of cervical carotid artery
- Thrombus filled in cervical carotid artery
- Intracranial stenosis
- Hemorrhagic stroke
- Resolving distal migration
- Solitaire stent getting stuck in cerebral arteries

Technical Tips (Exotic and Rare Case)

For advanced level operators

- Acute ischemic stroke due to aortic dissection type A
- Acute ischemic stroke due to head blunt trauma
- Acute ischemic stroke due to carotid fusiform aneurysm dissections

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